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ON THE PHENOMENA OF THE

GLACIAL DRIFT OF SCOTLAND

BY ARCHIBALD GEIKIE, F.R.S.E. F.G.S.

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OF EDINBURGH AND GLASGOW, ETC.

EXTRACTED FROM THE TRANSACTIONS OF THE GEOLOGICAL
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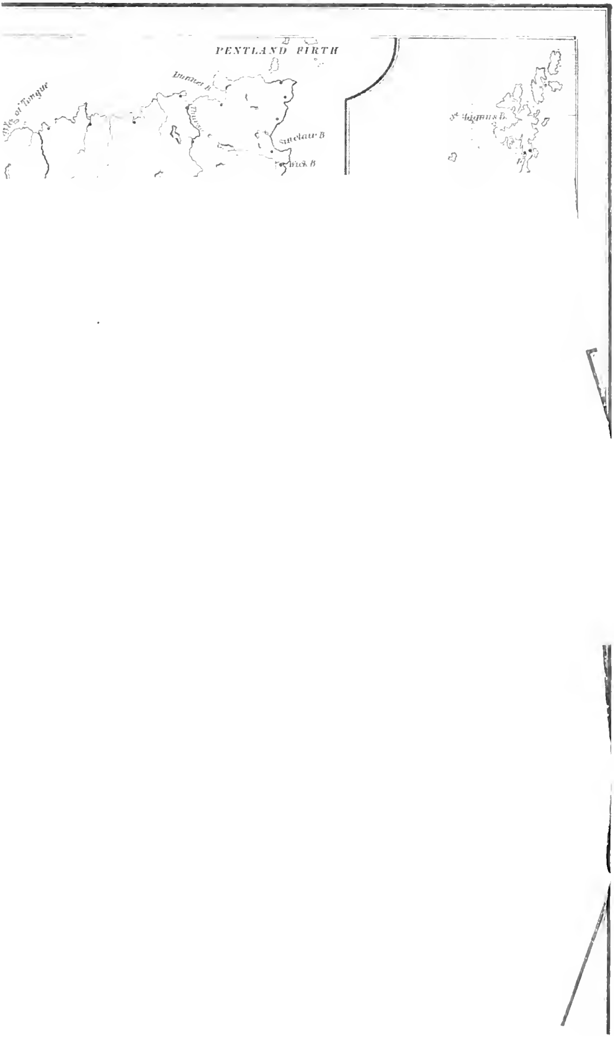
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PREFATORY NOTE.

A FEW words of explanation may be offered here regarding the origin and purport of the following fresh contribution to the already ample literature of the Glacial phenomena of Scotland. In the autumn of 1859, during the course of a geological ramble in Fife, my old friend and colleague, the President of the Geological Society, first led me to inquire more narrowly into the received theories respecting the cause of the dressed rock-surfaces, and the accumulations of boulder-clay. In company with nearly every geologist in this country, I was in the habit of regarding the striations on the hills of the opener parts of the country, as for instance in the valley of the Forth, as due to the abrading force of icebergs, by whose operations also the boulder-clay was held to have been transported over the surface of the submerged land. So thoroughly had I accepted this explanation, that the rejection of it became a matter of no little time and labour. It was not until the summer of 1861 that I finally abandoned the attempt to explain the origin of the rock-dressings and the boulder-clay by the action of icebergs. Professor Ramsay, who had in the meantime been studying evidences of ice-action in different parts of this country, as well as on the Continent, and comparing them with those which he had previously examined in Canada, had come to a similar conclusion. It appeared to us that iceberg-action was wholly inadequate to explain the origin either of the moulded and striated rock-surfaces, or of the boulder-clay. These phenomena seemed only explicable on the supposition that the whole of this country was covered with ice and snow, like large tracts of Greenland at the present day; and that, by the constant downward and seaward movement of this icy covering, the rocks were ground down, and the boulder-clay was produced.

Towards the close of 1861, being now fully satisfied of the untenableness of the currently-received hypothesis, I set myself to collect and read over all the papers which bore upon this branch of Scottish geology. The task proved somewhat more difficult than seemed at first likely; for though I was already familiar with a considerable number of papers on this subject, I did not imagine that there existed such a goodly array as that given in the subjoined Appendix, which is even itself confessedly imperfect. One result of this course of reading was to convince me that a more useful service could hardly be rendered to the cause of geology in Scotland than by collecting together the facts scattered through scores of papers, memoirs, and notices in various scientific publications, and grouping them in such a way as to convey as clear an impression as might be of the character of the phenomena from which the history of the Glacial Period is to be compiled. This object is partly attempted in the following pages. Where the facts had often been described, and lay open to the daily inspection of every one, as, for instance, in the case of the aspect of the rock-dressings, and the structure of the boulder-clay, I have, for the most part, written from my own observation, without the affectation of quoting previous writers. But in all other circumstances, in justice both to other observers and to myself, I have made it my duty to add full references to authorities. In addition, however, to a collation of the work of others, I have included the results of my own labours in this department of geology during the last six or seven years, more especially in the elucidation of the history of the boulder-clay; and unless where references to authors are given, the facts and arguments are stated as the results of my own observations.

Shortly after the commencement of this Memoir, viz., in

January 1862, in a course of lectures at the Museum, Jermyn Street, London, I explained at some length the reasons which induced me to reject the theory of icebergs as explanatory of the Drift, and to substitute for it the theory of land-ice. In February following, Professor Ramsay and myself had the satisfaction to hear these views ably confirmed by the independent observations of Mr. T. F. Jamieson, in a paper read before the Geological Society. Sir Charles Lyell has adopted the same explanation; and doubtless it will, ere long, come to be universally accepted in this country, as it ought to have been fully twenty years ago, when its first outlines were sketched by Agassiz.

Strengthened by the independent testimony of these geologists, I carried on the preparation of this Memoir in the intervals of other duties during the summer and autumn of last year (1862), and read it in abstract to the Geological Society of Glasgow on the 20th of November. Its passage through the press has been unhappily retarded in a way which I could neither anticipate nor prevent. It is now offered to geological students in Scotland, in the hope that it may prove of service in making them acquainted with the present state of the subject, and pointing out to them into what paths they may most usefully direct their steps. I have added a map on which are marked a few of the leading features of the Glacial phenomena of Scotland. It makes no pretension to be more than merely a first outline.

The beginning of the Appendix contains an expression of acknowledgment to several friends from whom, in studying the fossils of the Drift, I have received much valuable assistance. I cannot close this note without again expressing my obligations to my old friend, the Rev. A. Macbride of Ardmory, Bute, who not only placed his collection at my disposal, but by accompanying me to many localities where he had himself studied the structure and contents of the Glacial clays of the Clyde, gave me an acquaintance with those beds greatly more extensive than it could otherwise have been. His kindness has made my rambles in that district among the most delightful I ever enjoyed. To the Rev. H. W. Crosskey of Glasgow, also, I must again make my best acknowledgments. The trouble he has taken in assisting me in the catalogue of the mollusca of the Clyde beds, no one who does not know the terrors of zoological synonymy can in any measure appreciate. Dr. Scouler, too, has been ever ready with his valuable information and advice.

1st April 1863.

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APPENDIX.

ON THE GLACIAL DRIFT OF SCOTLAND.

Introduction.—There are certain features of Scottish scenery which may be traced everywhere throughout the island, without much regard either to the changes in the form of the ground, or to the varieties in the character of the geological formations. The glens and mountain-sides of the Highlands, the broad undulating expanse of the central district, and the pastoral uplands of the southern counties, notwithstanding their wide diversities of outline, have, nevertheless, certain aspects in common, which seldom fail to attract the notice even of the ordinary traveller. He is struck with the rounded and worn aspect of many of the hills, and can detect in their flowing outlines traces of some abrading agency, far other than that of the frosts and rains of winter. Spread out in thick masses over the Lowlands, and extending even for many hundreds of feet up into the recesses of the mountains, there are deposits of clay and boulders of the most irregular and tumultuous kind. Hummocks and mounds of sand and gravel everywhere abound, sometimes blocking up a Highland valley, or running in wavy ridges among the moors and corn-fields of the lower grounds. Blocks of rock, sometimes of great size, may be seen strewed over the valleys and plains, or perched on the sides and summits of the hills, many leagues from the nearest points from which they could have come. When the observer, in his passage through the country, is constantly brought face to face with these and other similar features, he is naturally led to associate them with some powerful agency which has operated on the rocks, irrespective of their age or composition. He remarks that since such phenomena occur, even among the newest rocks, they must be later than the great mass of the geological formations of the country, and that in short the general abrasion of the surface, with the production of vast masses of clay, sand, gravel, and boulders, must be one of the latest of the many geological revolutions which this part of the earth's crust has undergone.

It was natural, therefore, that in the infancy of Scottish geology, attention should have been early given to the problems suggested by the superficial accumulations. At a time when it was a common belief that the forces of nature once acted with a far higher intensity than they do now, the transport of the surface detritus, and the abrasion of the hills, were usually explained by reference to some vast currents or debacles of water, which, rushing across the country, tore up and transported huge quantities of sand and gravel, with large masses of solid rock. Playfair, however, pointed out that currents of water, even of the most stupendous kind conceivable, were wholly inadequate to transport huge blocks of stone, such as those on the flanks of the Swiss Jura, and that "for the moving of large masses of rock, the most powerful agents, without doubt, which nature employs, are the glaciers."[1]

Notwithstanding the eloquent protest of the defender of the Huttonian Theory, and his sagacious inferences as to the transporting power of ice, the opinions which he opposed continued to maintain their ground. In the year 1809, Bald described with accuracy the character of the boulder-clay that overlies the Clackmannan coal-field, without, however, attempting to theorize as to its origin.[2] Three years later, namely, in the early part of 1812, Colonel Imrie called attention to the Campsie Hills as affording evidence of powerful denudation. The hard trap-rocks, he showed, had been scooped out into deep glens and ravines, the crags had been rounded off, smoothed, and scratched, while immense masses of rock lay scattered about on the hills. From the general trend of the ridges and furrows, and the direction in which the boulders lay, he inferred that great bodies of water rushing from west or north-west ploughed out

[1] *Illustrations of the Huttonian Theory* (1802), § 349. See also *Works*, vol. i. p. 24.

[2] *Mem. Wer. Soc.* i. 481.

the hollows across the hills, and tore away fragments of the rock which, in turn, smoothed and furrowed the hard surfaces over which they were driven.[1]

It was in the summer of the same year that this hypothesis of violent floods, so far at least as it related to the geology of Scotland, was first elaborated into a system. Sir James Hall now communicated to the Royal Society of Edinburgh his remarkable and well-known paper "On the Revolutions of the Earth's Surface."[2] He, too, drew attention to the proofs of vast denudation everywhere observable in his native country, to the smoothed and striated surfaces of its rocks, to the abrupt western faces and sloping eastern declivities of its hills, to the dispersion of boulders, and to the character of the boulder-clay or till. He still sought to explain these phenomena by the agency of sudden and violent debacles, but he endeavoured to do so by a process of strictly inductive reasoning. Founding on the observed effects of freshets in rivers, and on those of the powerful breakers thrown on shore by the operation of earthquakes, he inferred that the boulder-clay and the grooved and polished rock-surfaces pointed to a time when vast bodies of water, set in motion by violent earthquakes, and laden with

[1] *Mem. Wer. Soc.* vol. ii.

[2] *Trans. Roy. Soc. Edin.* (1812), vol. vii. Several years before this, he had announced his belief that vast torrents, so deep as to overtop mountains, had swept across the surface of the country (*Trans. Roy. Soc. Edin.* v. p. 68, footnote), and he then promised to investigate the subject more thoroughly. During the interval that elapsed between this promise and its fulfilment in the publication of his great paper in 1812, Playfair's *Illustrations* appeared. In the latter work there occurs a reference to the forthcoming memoir (footnote to § 367). The idea which Sir James worked out was not original. Indeed, he refers expressly to the coincidence of his views with those of Pallas, De Saussure, and Dolomieu. But it was his great merit to have sought to rest the hypothesis upon a basis of well-authenticated facts, and not merely of speculation. Playfair, in contending against this doctrine of sudden and violent floods, complained of the vagueness which characterized the statements of those who maintained it. "Neither Pallas," he says, "nor Saussure, nor Dolomieu, nor any author who has espoused the hypothesis of the action of sudden and irregular causes on the surface of the earth, has explained his notions with any precision; on the contrary, they have all spoken with such reserve and mystery as seemed to betray the weakness, but may have concealed the strength of their cause. I have, therefore, been combating an enemy that was, in some respects, unknown; and I may have supposed him dislodged only because I could not penetrate to his strongholds."—*Illustrations of the Huttonian Theory*, § 367.

mud and stones, swept across the country. He describes, in detail, some of these "dressed rocks," as he called them, near Edinburgh, and showed from their position that the current of water must have set from west to east. He maintained that the whole phenomena of the superficial accumulations pointed to a stupendous wave or debacle that had swept across the country.[1] Sweeping from the west or north-west, it rushed eastward along the central valley, grinding down the surface, and leaving the harder rocks as prominent crags, each with a tail of detritus heaped up on its lee. Part of the torrent, arrested by the high lands of Ayr, Kirkcudbright, and Dumfries, rushed back, thus scooping out narrow and broken defiles and valleys, and, at the same time, equalizing the general declivity of the West of Scotland.

Such was the hypothesis by which one of the most acute and original minds that ever entered on the study of the geology of Scotland, proposed to interpret the phenomena of the Drift. Unsatisfactory as it was, it yet formed the best explanation which could be given, so long as moving water was regarded as the agent by which these phenomena must have been produced. Dr. Buckland, in the year 1811, and again, along with Sir Charles Lyell, in 1824, observed grooved and polished rocks in various parts of Scotland, but, like other geologists of the time, he attributed them to diluvial action.[2] He even sought to identify such appearances with the effects of the Noachian deluge—an opinion that was vigorously opposed by the late Dr. Fleming.

The impossibility of accounting by great currents of water for several of the superficial phenomena of the geology of the country, early suggested itself to Professor Jameson, and we

[1] In a footnote to his paper (*Edin. Roy. Soc. Trans.* vol. vii. p. 195), Sir James remarks: "Having endeavoured to illustrate the appearance of the dressed surfaces, by referring to abraded rocks in the beds of rivers, I find that some gentlemen conceived it to be a part of my supposition that these dressings, like those in a river, were produced by water acting for a long time. But this is by no means my view; my theoretical notions limit the action upon the hill under examination to the passage of a single wave, embracing a period of time that could only be expressed in minutes; but during that short time, I conceive the water to have been urged forward with such force, and to have carried with it so many powerful agents, that it has produced effects equal to the work of ages under other circumstances."

[2] *Proc. Geol. Soc.* vol. iii. p. 332.

find him, in 1827, suggesting to his class that possibly such facts were to be accounted for by the agency of ice.[1] But I have not been able to ascertain that his views were ever published.

In 1828, Mr. Maclaren published in the *Scotsman* newspaper some valuable notices of the nature of the till and boulders in the neighbourhood of Edinburgh. Ten years afterwards, he collected them, along with the results of subsequent observations, and published the whole as a chapter in his classic work, *The Geology of Fife and the Lothians*. He continued to regard the phenomena of "crag-and-tail," and the grooving and polishing of the rocks, as due to the agency of currents setting in from the west. But he pointedly showed that these could not have resulted from one sudden debacle; he stated his belief that they were produced by degrees, and in varying intensity during a long period of time; he attributed them to the action of marine currents set in motion as the currents of the ocean are at the present day; and, with De la Beche, Lyell, and others, he recognised the agency of icebergs as having been probably concerned in the transport of the boulders.[2]

Mr. Milne Home, in an elaborate paper on the Mid-Lothian and East-Lothian coal-fields,[3] gave details of the structure of the boulder-clay, sand, and gravel, which cover that district. He referred these deposits to the action of powerful oceanic currents.

While these observers were at work among the Drift deposits of the east of Scotland, there was in progress among the picturesque sea-lochs of the Clyde a remarkable series of observations, destined ultimately to cast much light on the complex history of the superficial accumulations of the country. Happy in the possession of a yacht, and with the command of ample leisure, Mr. Smith of Jordanhill had for years been tracing the existence of beds of marine shells at various heights above the present sea-level. He had found them so persistently round the

[1] See footnote to a paper by Principal Forbes (who was a pupil of Jameson's). —*Edin. New Phil. Jour.* vol. xl. p. 99.

[2] *Geology of Fife and the Lothians*, pp. 207-227.

[3] Read before the Royal Society of Edinburgh in 1838, and published in vol. xiv. of the Transactions.

coast-line of the west of Scotland, that he felt himself bound to conclude that the land had been elevated within a very recent geological period. His first paper was communicated to the Geological Society towards the close of the year 1836. As his investigations proceeded, however, he was surprised to find, that not a few of the shells in these elevated deposits were not now natives of the adjoining sea; and when more narrowly scrutinized, they proved to be to a considerable extent identical with species now inhabiting the Arctic seas. Early in 1839, therefore, Mr. Smith communicated this fact to the Wernerian Society, and drew from it the natural inference, that at a comparatively late geological period the climate of this country must have been greatly colder than it is at present. He did not, however, regard these marine shell-beds as having originated under any of the conditions necessary for the accumulation of the underlying *till* or boulder-clay. On the contrary, he still regarded the till and the dressed rocks as evidence of violent rushes of water, and the fine shell-bearing clays, as marks of a tranquil sea-bottom, belonging to a later and a very different geological era.[1] It was not until some years later that the high importance of his researches in their relation to the history of the Drift was generally perceived.

Up to this time, therefore, notwithstanding the gradual increase of observed facts, it can hardly be said that much advance had been made on the original speculations of Sir James Hall. His violent floods had by some geologists been discarded for the less powerful, but more certain operation of ordinary marine currents, and what he had supposed to be the work of a few moments, was thus viewed as the collective result of long centuries of waste. And yet, if we were to seek the explanation of the till and the dressed rocks by reference to the effects of moving water alone, it may perhaps be questioned, whether the hypothesis of Hall would not afford a more probable solution of the problem than could be found in any of the recognised operations of even the most powerful marine currents. This at least seems certain, that no current has yet been observed to produce such results as the boulder-clay, dressed rocks, and "crag and tail" of Scotland. On the other hand, if we could

[1] See his Collected Papers published this year (1862), pp. 2, 3, 28, and 44.

grant the possibility of such Titanic floods as Hall required, it is perhaps conceivable that they might effect some of the results which he claimed for them. In the one case, we have phenomena attributed to a cause which cannot be shown to have ever existed, but which, if it had existed, might have partially produced them; in the other, we see phenomena assigned to an agency which certainly does exist, but which seems wholly inadequate to perform what is required of it.

The chief addition to the agents demanded by Hall's hypothesis, was the introduction of *ice* as a means of transporting large masses of rock. Though the carrying power of ice had been so clearly pointed out by Playfair at the beginning of the century, yet his remarks for thirty or forty years appear to have been altogether forgotten.

Hardly, however, had the speculations of Mr. Smith appeared, preceded and accompanied as they were by those of Sir Charles Lyell on the upraised deposits of Sweden and the sands and clays of Norfolk,[1] when light from a new quarter began to dawn on the dark and obscure history of the Drift. Already in an address read before the Helvetic Natural History Society in the summer of 1837,[2] Agassiz, following up the suggestion of Playfair and the bold speculations of Venetz,[3] announced his belief that Switzerland had once been sealed in ice, that its rocks owed their present grooved and polished surfaces to the passage of this icy sheet over them, and that to the same cause was due the transport of enormous blocks of stone from the Alps to the Jura.

In the following year, Dr. Buckland, under the guidance of the Swiss naturalist, examined these phenomena on the spot, and by witnessing the effects of actual glaciers, became convinced that the grooving and striation of the rocks of the British Isles, and the position of the erratic blocks there, though now far removed from any glacier, were, nevertheless, due to the same agency which is now grinding and polishing the sides of the higher valleys of the Alps.

[1] See *Phil. Trans.* for 1835; *Phil. Mag.* May 1840; *Proc. Geol. Soc.* iii. 171.

[2] *Edin. New Phil. Jour.* xxiv. 364.

[3] *Trans. Nat. Hist. Soc. Switzerland.* vol. i. Part 2, referred to by Professor Forbes. *Travels in the Alps.* p. 43.

In 1840, Agassiz visited Scotland, and spent some time in traversing the country with Dr. Buckland. The result of this tour was to commence a revolution in the received opinions regarding the origin of the Drift.

Agassiz found, as his companion had led him to expect, that Scotland exhibited the most unequivocal proofs of having been the seat of glaciers. The dressed rock-surfaces he recognised at once as strictly the same with those which he knew so well in Switzerland. The travelled blocks, too, which had for so many years been appealed to as among the strongest proofs that vast currents of water had swept across the island, he saw to resemble in many respects the erratics of the Alps. So far from any indication of a general movement of the supposed current from the west or north-west, he found that the agent which had transported the blocks had diverged from the main axis of the country, and had descended into the valleys. Thus, in the valleys of Loch Lomond and Loch Long, the direction of transport appeared to be from north to south; in those of Loch Fyne and Loch Awe, from north-east to south-west; in Loch Etive and Loch Leven, from east to west; and in the valley of the Forth, from north-west to south-east, radiating from the great mountain masses between Ben Nevis and Ben Lomond. From the analogy of the phenomena in Scotland, England, and Ireland, with those of Switzerland, Agassiz concluded that "not only glaciers once existed in the British Islands, but that large sheets (*nappes*) of ice covered all the surface;" and that the nearest existing parallel to this condition of things was to be found in the ice-fields of Greenland. He held, moreover, that at a subsequent period the quantity of ice had so far lessened as to exist only in the form of local glaciers which descended the valleys and left moraines like those of Switzerland.[1]

Whilst Agassiz and Buckland were tracing the remains of ancient glaciers among the south-western parts of the great range of Highland mountains, Sir Charles Lyell was conducting similar but much more minute investigations farther to the north-east. In the upper recesses of Forfarshire he found several glacier moraines; he attributed the unstratified till to the action of glaciers, and clearly recognised the presence of

[1] *Proc. Geol. Soc.* vol. iii. p. 327.

drifting ice during the deposition of the stratified Drift. Of these remarkable observations he published an account simultaneously with the memoirs of Agassiz and Buckland.

Although the two latter geologists appear sometimes to have mistaken mounds of river or marine sand and gravel for glacier moraines, there can be no doubt that their explanations were right in the main. From this time onward the glacial origin of the rock striations, and the former existence of glaciers in Britain, came to be universally acknowledged, but the explanation proposed by Agassiz was only partially accepted. While it was admitted that glaciers had descended the main valleys of the Highlands and of Wales, and while descriptions of their moraines accumulated year after year,[1] British geologists were reluctant to admit that sheets of ice could ever have covered the lowlands at the distance of many leagues from the mountain chains. They, therefore, preferred to attribute the smoothing and grooving of the rocks in the low-lying districts, with the accompanying deposits of till, sand, and gravel, to the action not of sheets of land ice, but of icebergs, floating from the west and north-west, and dropping over the submerged land their burden of mud, sand, and stones. The accumulation on the sea bed of the sediment and boulders thus thrown down was held to have produced the deposit which is known as the till or boulder-clay, and the rock surfaces were supposed to have been striated by the passage across them of the stone-laden bergs.[2]

Yet there were some geologists who saw that there existed phenomena for which iceberg action would not account. My friend and colleague Professor Ramsay, while admitting the submergence of Wales to the extent of upwards of 2000 feet, pointed out that beneath the marine drift produced during this depression, the surface of the rocks was striated and smoothed in the same manner as it was in the valleys which could be shown to have been occupied by glaciers since the elevation of the land. He inferred that before the submergence, therefore, there had been an extensive development of glaciers, as well as a more limited display after the re-elevation.[3]

[1] See especially the admirable paper by Principal Forbes on the old glaciers of the Cuchullin Hills.

[2] Lyell, *Elementary Manual*, last edit. (1855), p. 138.

[3] *Quart. Jour. Geol. Soc.* viii. (1851-2), p. 371.

Mr. Robert Chambers has strenuously and ably opposed the iceberg hypothesis. At the close of the year 1852, he read to the Royal Society of Edinburgh an elaborate paper on glacial phenomena in Scotland and parts of England.[1] In this essay he enumerates instances observed by himself and others, of striated rocks occurring in situations where they could not have been reached by any ordinary glacier, and yet the striations were in every respect comparable with the known results of glacier movement. He describes the general rounded and "moulded" outlines of the island as evincing the operation of a general and powerful abrading agent, far more uniform and persistent in its action than icebergs. "If any man," he remarks, "were to say that because he can, with some difficulty, smooth a rough surface of wood with his thumb-nail, therefore his dining-tables must have been fashioned and polished with that little instrument alone, I would consider him as advancing a theory fully as tenable as that which consists in attributing all the so-called glacial phenomena to icebergs." Mr. Chambers conceives that during the period represented by the boulder-clay, there was a vast southward extension of the circum-polar ice, and that this sheet of ice extended completely over Scotland, slowly creeping from the north or north-west, and grinding down the surface of the country as it passed.

More recently several able geologists have begun to throw doubts upon the commonly received iceberg hypothesis, and to adopt the explanation proposed by Agassiz. Professor Ramsay and Mr. T. F. Jamieson have come to this conclusion, and I believe I may add the high authority of Sir Charles Lyell. Nevertheless, it is I believe true that the iceberg hypothesis still remains the generally accepted explanation of the phenomena of the striated rocks and the boulder-clay. Its untenableness seems to me completely established, but this will better appear after the phenomena on which the different theories of the drift are based, have been described. It need only be observed at present that how much soever geologists may differ in their views of the mode in which the ice acted during the deposition of the various members of the Drift series, they are agreed that ice, in some form, has had a chief share in the pro-

[1] *Edin. New Phil. Jour.* liv. 229, *et seq.*

duction of that series of deposits. In the succeeding pages I need not hesitate, therefore, to speak of *glacial agency* as concerned in the origin of the phenomena, even before proceeding to inquire to what conclusions these phenomena appear to lead. Nor will it, perhaps, be always possible to defer allusion to what I regard as the true theory. But I reserve the full statement of this theory until the nature of the drift and its associated rock-dressings have been described in detail.

Subdivisions of the Drift.

It is extremely rare to find all the members of the Drift present in one locality. Arranged according to their order of superposition, they are found to rest on rounded and striated rock surfaces, and to consist first, of a stiff clay or earth (sometimes, but rarely covering stratified sand or clay), full of stones, of many different sizes, and widely known as the till or boulder-clay. This is overlaid by a series of sands, gravels, and clays, which in some places are full of marine shells. The boulder-clay is unstratified; the stratified deposits which overlie it are not all contemporaneous, but belong to successive parts of the Drift period. The superficial accumulations in Scotland, therefore, when grouped in a tabular form, according to their relative antiquity, will stand thus:—

Lacustrine and fluviatile marls, clays, and silts, with peat mosses.
Raised beaches of post-glacial age.

DRIFT SERIES.
- Moraines.
- Brick clay and shell-bearing clay, usually on low grounds skirting the coast, and extending under the sea; with, perhaps, the forty-foot raised beach.
- Sands, gravels, and clays, with erratic blocks scattered over the interior of the country.
- Till, or boulder-clay (with occasional underlying stratified deposits) resting on
- Smoothed and striated rocks.[1]

In studying the structure and origin of the Drift deposits, we find that they naturally range themselves into three groups.

[1] It will be seen in a subsequent part of this essay, that some of the deposits given in the above table are not always to be discriminated in point of geological age. Some of the moraines, for instance, may be older or later than, or contemporaneous with the shell-bearing clays and other marine glacial deposits. The table is therefore only approximately true.

Of these, the oldest or boulder clay, points, as we shall see, to a period of intense cold, when the country existed as land, having on the whole the same great outlines of hill and valley as at present. The second group embraces the sands, gravels, and shell-bearing clays, and indicates a time when the land was submerged beneath the sea. The third division, that of the local moraines, shows that, after the island emerged from the sea, the cold still continued sufficiently severe to give rise to glaciers, which, descending from the main mountain ranges, ploughed out the deposits that had been left by the tides. It will, probably, be most convenient to treat the phenomena of the Drift as they bear on the history of these three periods. This arrangement has the advantage of retaining the strict chronological order, and at the same time, linking more closely together the facts which it is requisite to investigate. I shall therefore describe the traces of—

I. The Old or General Glaciation of the Country.

II. The Marine Submergence and Re-elevation.

III. The Final Disappearance of the Ice.

It would be highly important if we could detect in any part of Scotland, traces of the old land surface previous to the commencement of the reign of ice. The cliffs of Norfolk have revealed many circumstances of great interest touching the early part of the glacial period in the east of England. But in Scotland, so far as we yet know, the surface of the country seems to have been swept bare, its soil, vegetation, and animals removed, and nothing left but the subjacent hard rock, ground down, and finally obscured by the accumulation over it of its own detritus.[1] It is indeed possible, though far from likely, that vestiges of that early land may still survive. Certainly, Scottish geology presents few inquiries more worthy of an active prosecution than the search for some clue to the state of the island, and especially to the character of its plants and animals, immediately previous to the era of the boulder-clay. No opportunity should be lost by the students of the science of examining every section of the Drift which they can reach.

[1] The only exceptions to this remark, are the beds of sand, gravel, and clay occasionally found beneath the till. Some of these appear to be relics of ancient water-courses. They will be described on a subsequent page.

They should, above all, endeavour to explore more thoroughly the basement-beds of the formation, in the hope of possibly some day lighting upon a relic of the soil that preceded the till, with the remains of its trees, and perchance the bones of its animals. Till some such happy discovery is made, we must be content to borrow from other sources our ideas of the scenery of the Scottish hills and valleys ere they were cased deep in ice, and slowly settled down beneath the sea.

I.—The Old or General Glaciation of the Country.

The phenomena from which the history of the first part of the drift period is compiled, are the *rounded and scratched rock surfaces* and the *boulder-clay*. We may first attend to the nature and extent of these phenomena, and then proceed to investigate the conclusions to which they appear to point.

1. *Rounded and Striated Rocks.*

To the practised eye the surface of Scotland presents almost everywhere a peculiar rounded or moulded outline which the geologist recognises as a characteristic result of ice action. It is traceable in the wildest scenery of the Highlands, and throughout the bare rocky Hebrides ; the uplands of the southern counties with their grey granite hills and solitary tarns, show the same features. But nowhere do we see this swelling contour more complete than along the wide central valley from the shores of the Firth of Clyde eastward to those of the Forth and Tay. The high grounds of Renfrew and Ayrshire, stretching north into the heights of Kilpatrick, and thence into those of Campsie and the Ochils, abound in that union of prominent yet rounded crag and gently curving hollow which indicates the passage of the ice-sheet with hardly less clearness than the ripple on the shore tells of the retreat of the sea. On the isolated eminences also which rise so conspicuously from the undulating plains of this district the same outline may be traced. We see it on the rock of Stirling Castle, on the heights of Linlithgow, on the group of rocks that surround the metropolis, on the hills of East Lothian and Fife, and on all the rocky islets of the Forth, from Bimar to the

Bass. Though modified in many different places by the effects of subsequent atmospheric waste, it is, nevertheless, a kind of outline which can seldom be mistaken. When a geologist has once familiarized himself with its varieties, even in one locality, there are not many landscapes in the country where he will fail to detect its presence.

Roches Moutonnées or dressed rocks.—This appearance, however, does not characterize merely the larger features of the scenery. Not only do the hills, when looked at from a distance, wear the aspect of having had their crags and knolls shorn down or rounded off, but the crags themselves exhibit the same structure in detail. They have a general undulating form somewhat like that of huge woolsacks or pillows, with smooth hollows and dimples between. The surfaces of such ridges and furrows, where they have been preserved from the influences of the weather by clay or turf, are sometimes as even as a piece of ashlar-work. It is true that, as with the outlines of the hills, so with that of their component knolls, the action of frost, rain, and other causes, has often split up the rock and worn it away, thus effacing its flowing lines and replacing them with a set of rough and irregular craggy surfaces. In this way the rounded form, in not a few cases, has ceased to be traceable. Yet in many instances, even where at first sight we seem to see nothing but an amorphous mouldering crag, with its joints and fissures worn into hollows, and the rock between them wasted into rude, rough blocks, a little examination will enable us to trace the curved outline still. It is no uncommon thing to find on one hill-side knolls in all stages of decay; one or two having only been recently uncovered, retain as freshly as ever the moulded character; some have begun to lose it as they yield to the combined agencies of atmospheric waste, while from others, gnarled and mossy, it has wholly passed away.

The smoothed surfaces of the rocks are further marked with a set of finer groovings, ruts, and striæ, corresponding in direction with that of the larger hollows. It was this structure, as shown on the western front of Corstorphine Hill near Edinburgh, which arrested the attention of Sir James Hall, and directed the notice of geologists to the superficial markings on the rocks of Britain. Since the days of that eminent philosopher observations have vastly multiplied, so that similarly dressed surfaces have now been detected everywhere, from the Pentland Firth southward into England. The number and size of the scratches vary indefinitely. In some places, they run as mere hair lines along the beautifully smoothed and polished surface of the rock; in others they are deeper and broader, passing even into ruts like those of a cart-wheel, or like the flutings of a Doric column. They may be traced keeping parallel with each other for some way, each of the striæ, though itself, perhaps, only an inch or two in length, pursuing its own course without crossing those of its neighbours. Even where they cross each other obliquely a general trend of the striations may still be traced. With regard to the distinctness of these markings, much depends upon the lithological character of the rock on which they are impressed, and on the length of time during which they have been exposed to the action of the weather. A hard, compact limestone may be observed to retain its dressings more freshly than any other rock. When the surface covering of clay is removed every scratch may be traced as a white line along the dark polished surface of the stone, reminding one rather of the precision of a diagram than of the rude handiwork of the elements. The removal of the boulder-clay, however, and a consequent exposure to the influence of the weather, soon tend to obliterate the finer markings, until, by degrees, the whole are effaced. Many limestone quarries in different parts of the island afford admirable instances of these polished and striated surfaces. One was visible a few years ago at the Cat Crag near Dunbar, and another was laid bare by the removal of a thick covering of boulder-clay at the silver-mine quarry, Linlithgow. In the latter instance the limestone, of a dark leaden colour, presented a smoothed surface completely covered with scratches. There were long grooves or furrows, the sides and bottom of which had the usual smooth and striated surface, while the rock was further marked with dimples or little hollows which were completely smoothed and scratched like the rest of the rock. The hard basalts, greenstones and felstones, also retain in great perfection their glacial dressings. The same markings are still easily recognisable on the grey gneiss and schist mountains of the Highlands. They are equally well seen on the old Cambrian and Laurentian rocks of the north-west, and even on the flinty hypersthene of Skye. They may be traced also on the grauwacké hills of the southern counties, from St. Abb's Head to Portpatrick. In short, there is hardly any kind of rock on which they may not be found, provided its surface has been sufficiently shielded from the weather. Nay, even exposure to the rains and frosts, or to the beating of the waves during many centuries, has sometimes been unable to efface them.

Universality of Striations.—No feature of these rock-dressings is more impressive than their universality. Mr. R. Chambers has remarked with truth that the difficulty is not to point out where they are to be found, but where they are not. Scarcely a new quarry is opened without disclosing them. Wherever indeed the boulder-clay mantle is taken away, either by the agency of the elements or by man, the rock exposed below it is almost invariably found to be smoothed and striated. They are seen along the bare tops and sides of the Highland mountains, and they everywhere underlie the rich corn-fields of the Lowlands. It would hardly be an exaggeration to say that the whole surface of the island, from Cape Wrath to the Solway, is smoothed and striated. Nor do these markings cease with the limits of the land; they are again and again seen plunging away under the sea, so that the bed of the German Ocean and that of the eastern portion of the Atlantic, may be as thoroughly striated and polished as the surface of the land.[1]

Directions of Striations.—It has been supposed by some writers—Sir James Hall for instance—that the grooved and striated rocks of Scotland are, as a whole, directed from west to east, or from north-west to south-east. This, however, is true only of a limited district. In the Lowlands the trend is certainly in this direction, but no sooner do we advance into the Highland tracts, than we find a wide divergence from the supposed rule. We discover, as was pointed out by Agassiz, that the striations bear a general relation to the main lines of valley, and radiate

[1] It would be out of place here to do more than merely refer to the fact that this striation of Scotland is only part of one vast system of polishing and grooving which has altered the aspect of the whole of Northern Europe and Northern America.

outwards from the higher mountain ranges. It may be of advantage to examine somewhat at length the evidence on this point. And first, as to the surface markings in the Highlands.

The mountains of Sutherland and Ross afford many fine examples of true *roches moutonnées*. Nowhere can the bossy, mammillated outline already described be better seen than along the surface of the belt of old Laurentian gneiss which fringes the western shores of these counties. On almost all the deep fiords, the exposed rocks show well-marked grooves and striæ running as a whole parallel to the direction of the valleys, or from south-east to north-west. Some parts of the sides of Loch Broom are especially rich in these markings. A short way north of Ullapool the dull red Cambrian sandstones sweep down in thick masses to the margin of the sea, and their surfaces, when bared of the overlying drift and turf, are rounded, smoothed, and covered with striæ, of which the direction corresponds to that of the loch, *i.e.*, from south-east to north-west.

Again, along the northern shores of Sutherland, we find that the white quartz-rock which encloses Loch Eribol is ground smooth, and covered with striæ running from SSW to NNE, which is here the trend of the valley. The west side of the Kyle of Durness shows the same quartz-rock marked with horizontal striæ, which also point SSW and NNE, thus agreeing in like manner with the line of the loch.[1]

On the east side of the same county, fronting the North Sea, striæ have been observed by Professor Nicol on the white oolitic sandstone of Braambury hill near Brora. They run in an east and west direction towards Loch Brora and the heights of Ben Horn.

But both in Sutherland and Ross the same kind of markings may be seen even high on the flanks of the mountains, where they could not have been produced by the descent of any ordinary glacier. Mr. Robert Chambers has observed them on the craggy sides of Queenaig and Canisp. On the first of these magnificent mountains the striations could be traced up to a height of 1700 or 1800 feet; on the latter, to an elevation scarcely lower. The quartz-rock surfaces are marked with

[1] Nicol, *Brit. Assoc. Rep.* (1855), Sect. p. 88.

black streakings which, with certain exceptions, point to about N 60° W. Again, on the east side of the Assynt valley, to the south of Ben More, and about four or five miles from Canisp, the same observer has detected, on a summit fully 1500 feet high, striæ having a WNW and ESE direction. Markings of a similar kind were also found by him at an elevation of at least 2000 feet on Ben Eay—a huge mountain of quartz-rock which guards the head of Loch Maree. He records other north-westerly striations as occurring on the dreary, elevated valley of the Dirry-More, others eastward still on the highlands that look out upon the Pentland Firth, and some occasionally seen even among the lonely moors of Caithness.[1]

Along the great valley which stretches from Loch Carron, across the island to the Firth of Cromarty and Beauly, smoothed and striated rocks may be seen in many places. Professor Nicol has remarked that, in Strath Garve, the striations run from NW to SE, and in Strath Bran from east to west, in each case parallel to the direction of the main valley. Towards its west end, in the fiords that converge towards the Sound of Skye, the same observer has noted a similar relation of the striæ to the trend of the deeper glens.

At the upper end of Loch Keeshorn the striations on the red sandstone run north and south, corresponding to the line of the loch. On the east side of this inlet, in the narrow valley followed by the road to Jeantown, the striæ run west by north, or nearly at right angles to the former. On the ridge and hill-tops, between Balmacarra and Kyleakin ferry, the striæ are again south by east; while at the foot of Keppoch Hill and Loch Duich they run along an overhanging cliff from SE to NW, *i.e.*, parallel to the loch. There appears, therefore, to have been a general movement down the main valleys and across the lower ridges towards the present Kyles of Skye.[2]

I know of no better example of the striated surfaces now under review than that which is afforded by the island of Raasay, lying between Skye on the west, and the Ross-shire coast on the east. The absence of all bounding mountains prevents the possibility of confounding these markings with the operation of

[1] *Edin. New Phil. Jour.* liv. p. 250.
[2] Nicol, *Brit. Assoc. Rep.* 1855, Sect., p. 88.

any mere local glacier. The direction of the principal part of the island is nearly north and south, *i.e.*, parallel to the adjacent mountainous grounds of Skye and the mainland. Its highest point rises about 1500 feet above the sea, and is situated near the eastern margin of the island which, along this side, shoots up abruptly from the beach in a precipice of sometimes 900 feet in height. There is thus an undulating slope from the eminences on the east side of the island to the sea on the west. A number of hollows and valleys indent this slope more or less at right angles to its descent. The ridges which rise between these valleys show the characteristic rounded outline, with the long and deep furrows, as well as finer striations already described. It is to be observed that hollow, ridge, grooving, and striation, run along the slope of the island, and not down from the high levels to the sea. The whole island, in short, is smoothed and striated from end to end, irrespective of the inequalities of the ground. At the south end of the island, facing Scalpa, the striations on an abrupt face of red sandstone run from S 30° W to N 30° E, the direction of this part of the deep, narrow passage between the two islands, and in a line pointing to the great mountainous group of the Cuchullin hills in Skye. But from this point northwards, over the whole of the sloping declivities, the prevailing direction of the grooves and furrows is NNW and SSE, which is the trend of the great bank of high land that forms the southern half of Raasay. It is some years since these observations were made, and though I noticed the directions of the striations, not being specially occupied with the study of the Drift, I neglected to ascertain whether there was any evidence from which quarter the movement of abrasion proceeded. My impression is that it came from south to north, *i.e.*, from the high grounds of Skye, down into the sound of Scalpa, and thence along the slopes of Raasay.

In Inverness-shire the same phenomena are observable. Down the deep and narrow sea-lochs, as well as the glens and passes which lead into them, the rocks are rounded and covered with dressings. The savage defile, for example, which, in the short space of a mile, descends from the watershed of the country (here a thousand feet high) to the level of the sea at the head of Loch Hourne, is smoothed from end to end. All the rock faces that look up the glen are rounded off, while those pointing seawards retain much of their original ragged character. The long rounded ridges of rock, with their polished and striated surfaces and their blunted landward aspect, exactly resemble the true *roches moutonnées* of a glacier region. I am not at all certain, however, that this and some other instances of the same kind are strictly coeval with the striations now under discussion. In their present state they may be examples of the operation of the later and localized glaciers which, descending valleys whose sides had been previously polished and grooved, would of course obliterate the original striations, and leave another similar series upon fresh faces of rock.

The dressed rock-surfaces are by no means confined to the fiords that widen out into the open sea. We find them not less marked in the deep inlets that diverge from Loch Linnhe, as well as in the valleys that abut upon the line of the Great Glen. Thus on the shore of Loch Leven, close to the Ballachulish Ferry, there are two outliers of the neighbouring granite mountain which are described by Mr. Maclaren as rounded, polished, and covered with parallel grooves, generally one inch broad, and "so uniform and close together, as to remind one of the flutings of a Doric column." These markings face the north-east and north, and disappear where the rock begins to look towards the north-west, the roughest part of the rock being the west side. It is manifest therefore that the abrading agent came from the north-east, that is, downward from the high mountainous tract that stretches south-eastward from Ben Nevis.[1] Before alluding to some of the inland glens in this district, I shall add a few more notices regarding the sea-lochs farther south.

Along the mouth of Loch Etive, Mr. Maclaren also noticed that the ridges of rounded and polished rocks do not run parallel to the course of the valley, that is, from east to west, but point ESE and WNW, as if produced by some agent coming from Loch Awe, which is ten miles distant, and divided from Loch Etive here by hills from three to five hundred feet high.[2]

Many of the islets in Loch Awe seem to be low abraded domes of rock, and dressed surfaces are to be seen on both sides of the lake.[3]

[1] *Edin. New Phil. Jour.* xlvii. p. 170.

[2] Maclaren, *Edin. New Phil. Jour.*, *loc. cit.* [3] *Ibid.* p. 168.

The deep fiords that open out upon the Firth of Clyde abound in striking examples of striated rocks. Thus in Loch Fyne, as observed by Mr. Maclaren, the striations are seen running NNE and SSW, that is, along the line of the loch. The Duke of Argyll has shown that they retain the same direction even along the hill tops between Loch Fyne and Loch Awe, 1800 feet above the sea.[1] Mr. T. F. Jamieson has since observed that these markings continue from the upper part of Loch Fyne, and cross obliquely the high grounds of Knapdale into the Sound of Jura. They run *up-hill* round and over a slope seven or eight hundred feet above the sea. The whole surface here is beautifully smoothed and furrowed, and is dotted over with small lakes. The same markings still hold on across the high grounds, the knolls invariably presenting rounded blunt faces to the north-east, and more ragged edges towards the opposite quarter. It is evident therefore that the agent which produced this worn and polished surface must have moved down Loch Fyne, ascended the heights of Knapdale, and plunged sea-ward again towards the Sound of Jura.[2]

This is not the only example of the divergence of the striations and furrowings from the line of one sea-loch across intervening high grounds into the line of another. Thus, the long valley that crosses from Loch Fyne to the head of the Holy Loch, and in which lies the fresh-water Loch Eck, shows a striking succession of smoothed and polished rocks along its course. The striæ at the north-west end of this valley clearly indicate that the agent which produced them must have come slanting over from Loch Fyne. The same fact is also observable in some of the adjacent valleys. On the ridge that separates the Gareloch from Loch Long, at a height of 600 feet above the sea, striations occur at many localities having a trend from NNW to SSE. Mr. Maclaren has argued with reason that there is no centre from which a glacier of the ordinary kind could descend the Gareloch. The position of these striated rocks is thus of the highest importance, when we speculate on the origin of the general striation of the country.[3]

[1] *Proc. Roy. Soc. Edin.* iii. 459.
[2] *Quart. Jour. Geol. Soc.* xviii. p. 177.
[3] See Maclaren, *Ibid.* p. 165. Chambers, *Op. cit.* liv p. 255.

On the east side of the north end of Bute, some remarkable instances occur, in which the hard quartzose schists have had their edges shorn off, deeply grooved and well polished in a direction more or less at right angles to the direction of the narrow Kyles. I was much struck with one boss of rock at Balnakeally Bay, a locality rendered classic in geology by the fact, that there Mr. Smith first ascertained the existence of Arctic shells in the upraised marine deposits of the west of Scotland.[1] The rock occurs at the upper margin of the beach, and is well-furrowed, the smoothed parts looking down to the water, and the rougher faces pointing upwards and inland, as if the abrading agent had come up out of the sea, and climbed the slopes towards the interior of the island. The whole of the Kyles, indeed, abound in the most perfect examples of *roches moutonnées*.

But by far the most wonderful exhibition of the worn, mammillated, and striated rocks in this part of Scotland, occurs among the slate hills to the north of Loch Fad, one of a chain of deep fresh-water lakes which nearly cut the island of Bute into two. The hard metamorphized Silurian strata dip at high angles towards the south-east, and present in consequence their upturned edges towards the north-west. But instead of forming rough rugged crags as these rocks when left to themselves tend to do, the slates and grits are shorn down into the most perfectly smooth-faced knolls. The edges of the beds have been

FIG. 1.—View of *Roches Moutonnées*, near the summit of Barone Hill, Bute.

planed off obliquely, and the work has been done as cleanly and smoothly as if it had tasked the energies of all the masons

[1] See his Collected Papers, p. 29.

in Bute. Moreover, on Barone Hill, the top of which is about 520 feet above the sea, we see that the abrasion has been done by an agent which *came up* the steep northern face of that eminence, went right over its summit, and pursued its course down into the next valley beyond. The striations run on the whole nearly north and south, varying from N 15° W to N 20° E. The finer lines are usually effaced, though I found them still well marked on a quartz vein which protruded about the eighth of an inch above a smoothed surface of the schist. At the west end of Loch Du, which can be seen from the top of Barone Hill, the striations have been excellently preserved by a coating of boulder-clay recently removed. I believe this lake to lie in a true rock-basin, though the boulder-clay at the outlet prevented me from ascertaining this point with certainty. Such rock-basins are of frequent occurrence in districts that have been well worn and striated, and, as will be afterwards shown, they ought to be regarded as another evidence of the great denudation effected during the geological period now under discussion. The whole of this part of Bute is wonderfully moulded. The knolls, as a whole, present their smoothed faces to the north or north-north-east, while their opposite sides are more ragged. The numerous long hollows and valleys point in the same direction; so also do the striations. In short, the fact is impressed upon the observer at every step, that some agent of vast erosive power, moving from the north, has come obliquely across the strait that separates Bute from the mainland, passed steadily and triumphantly up and over all the hills and ridges of the island, only turning a few degrees to the right or left, according to the form of the ground, and that, grinding down the surface of the rocks into long parallel ridges and troughs, and scoring them over with ruts and striations in the same direction, this agent has finally passed over into the wide valley in which flows the sea-channel that separates Bute from Arran.

If now we turn eastward, and trace the valleys that descend to the east or south-east from the Grampian chain, we find similar evidence of a general abrasion, and of a close relation between the direction of the striæ and that of the main valleys. The great depression in which Loch Lomond lies is smoothed and striated from north to south, or in the line of its length, *roches moutonnées* being conspicuous at Bealmaha, Rowardennan, Luss, and Tarbet, while some of the islets, like those of Loch Awe, have the same mammillated character.[1] Mr. Robert Chambers has pointed out a remarkable example at the head of Loch Katrine, where striæ are seen to ascend obliquely out of the lake, passing over a high jutting hill promontory, reappearing under compact clay in low ground at some distance from the loch, and everywhere maintaining a direction from NNW. He thinks it probable, that the agent which produced these impressions came over a lofty range of hills from Balquhidder, passing on to cross a scarcely lower range and descend into the valley of Loch Ard.[1]

On the east side of Loch Lubnaig, the striations run north and south, or parallel to the lake, but as they pass down the valley they change to nearly east and west, on the top of the hill, which rises like a wall behind the village of Callender. The alteration in the direction of the groovings thus corresponds to a change in the trend of the valley.[2]

Again in the valley of Strathearn, the rocks are smoothed from west to east. One striking example is described by Mr. Maclaren as occurring at the west end of the village of Comrie, where a broad platform or ledge of clay-slate, projecting ten yards from the side of the hill above, is truncated at its eastern end, but terminates in a beautifully rounded and smoothed extremity to the west. It is traversed with grooves, from one-fourth to a full inch in breadth, which run straight as mathematical lines from WNW to ESE, exactly the direction of the strath.[4]

It thus appears that in the mountainous tract which extends from Loch Fyne to the Moor of Rannoch, and from Loch Linnhe to Strathearn, the striations on the rocks follow the direction of the main valleys. Mr. Maclaren in summing up the evidence presented by this district remarks: "On the east side at Loch Tay, the abrading and grooving agents moved eastward; on the west side, at Glen Spean, Loch Leven, and Loch Etive, they moved westward; and on the south side, at Loch Fyne, Loch Eck, Loch Long, and Gareloch, they moved southward.

[1] Chambers, *Edin. New Phil. Jour* liv. p. 255. [2] *Ibid. loc. cit.*
[3] Maclaren, *Edin. New Phil. Jour.* xlvii. p. 174. [4] *Ibid.* p. 173.

It follows that the nucleus of the physical force, the common centre from which the agents moved, was the group of mountains extending from Loch Goil northward to Loch Laggan, dividing the springs of the Spean, the Leven, and the Orchy, from those of the Spey, the Tay, the Earn, and the Forth. And the force must have resided in some substance, for the abrasion produced by it can be traced to the height of more than 2000 feet."[1]

Mr. Maclaren did not himself examine the districts to the north-east of this tract, but he suggested that the striations would be found there also diverging from the main chain of mountains. This has since been confirmed by Mr. Jamieson, who shows that along the east part of Aberdeenshire the direction of the grooves and striæ is from west to east, or from W by S to E by N, and that the rounded and polished faces of the rocks look towards the high grounds of the interior.[2] He has also pointed out that at the foot of Loch Treig—a locality which so forcibly arrested the attention of Agassiz[3]—the striations which descend from Glen Treig diverge on reaching Glen Spean, one series going away down the valley to the Great Glen, the other striking up Loch Laggan and crossing into Strathspey. It seems to me questionable, how far the existing striation of Loch Treig and the valley in its immediate vicinity are to be attributed to the early part of the Drift period now under review. It cannot, indeed, be doubted that during the general movement of abrasion which we are at present considering, the sides of Glen Treig and Glen Spean were powerfully ground down and polished. But it seems equally probable that the actual smoothed and striated surfaces, such as we now see them, have been to a large extent produced after the submergence of the country by local glaciers descending from the Ben Nevis mountains. I shall return to this question, however, at a subsequent part of the present paper.

The Lowlands of Scotland furnish equally striking proofs of a general and uniform abrasion of the rocks. In the great central valley that stretches across from the Firth of Clyde to the

[1] Maclaren, *Edin. New Phil. Jour.* xlvii. p. 177.
[2] *Quar. Jour. Geol. Soc.* vol. xviii.
[3] See *Edin. New Phil. Jour.* xxxiii. p. 222.

mouths of the Forth and Tay, the rocks, underneath a covering of clay or soil, are commonly found to be covered with striations which, on the whole, run in the direction of the valley, or nearly east and west. It is hardly necessary to give examples to show the minor divarications from this general trend. These will be best seen from the accompanying map. I may remark, however, that a divergence of the striæ can be traced from the mountainous tracts of Stirling and Dumbarton to the south-east and east, and then, following the line of the valley of the Lothians, to the east-north-east. Thus at Torwood, four miles north-west from Falkirk, Sir James Hall found them striking towards the east-south-east, from the Trosach mountains through the opening between the Lennox hills on the one side, and the steeper Ochils on the other.[1] They show the same direction on the north side of the Stirling valley, along the west shoulder of Dumyat, at a height of five hundred feet above the sea.[2] As they enter the valley of the Firth of Forth they begin to bend more towards the east, and slowly round northward to ENE, thus corresponding with the general line of the basin of the Forth between the Pentlands and Lammermuirs on the south, and the chain of the Ochils on the north.

The striations and mouldings of the rocks in a district so far removed from any chain of hills where glaciers could have existed, acquire a peculiar interest. We find them retaining their prevalent direction wholly irrespective of minor inequalities of surface; nay, even in many cases without regard to the obstruction of considerable hills. Throughout the Lothians, I have seldom found them deflected more than a few degrees from their general course. And this persistency marks their occurrence equally on the low and on the high grounds. Along the sea-margin at Granton, a well-striated surface of sandstone shows the characteristic east and west dressings, while Dr. Fleming noticed them on the Pentlands at a height of about 1400 feet. Mr. Maclaren records a remarkable instance of striations crossing the valley of the West Water of Dunsyre, at the south end of the Pentland Chain, 800 or 900 feet above the sea. They point east and west across the course of the

[1] *Trans. Roy. Soc. Edin.* vol. vii.

[2] Maclaren, *Edin. New Phil. Jour.* xlvii. p. 175.

stream, and not down the hill.[1] Such markings occur alike on the sides and tops of the hills wherever the rock has not suffered too much from the influence of the weather. And even where the fine striæ have disappeared, the deeper ruts or furrows, or the still broader mouldings, may still be often traced stretching in the prevailing direction. Thus, on the west front of Corstorphine Hill the grooves and striæ ascend the slope in an easterly direction. Similar striations were long ago noticed by Colonel Imrie on the tops of the Campsie hills.[2] The south side of Arthur's Seat, and an impending cliff at the foot of the southern slope of Blackford Hill, near Edinburgh, are also smoothed and striated in the same direction. In these two instances, it is manifest that the polishing and striation of the rock must have been effected by some agent that moved steadily along, and adapted itself to every inequality of surface over which it passed. At Arthur's Seat a deep, narrow gully has had its sides and bottom completely polished and striated in a direction parallel to its length; in the case of Blackford Hill, the *overhanging roof* of the cliff exhibits a surface precisely similar. The whole of the wide tract of country forming the basin of the Forth, has thus been ground down and smoothed by an agent which moved along the line of the great valley that separates the Highlands from the mountainous tracts of the southern counties.

In the uplands of the South of Scotland, I have detected evidence of what appears to be a divergence of the striations from the main mountain masses. Thus, in the valley of the Tweed at Dreva, the railway has laid open a surface of hard Silurian grit, on which the striæ run towards the north-east. The rough edges of the rock look down the valley, and the smoothed faces are turned towards the great mountain range of Cardon and Culter Fell, 2400 feet above the sea. In the valley of the Eddleston Water, a tributary of the Tweed, similar hard grits are striated down the direction of the water-flow, while on the north side of the chain of hills at Jeffrey's Corse, the striations descend a hill-side towards the north. The water-

[1] *Edin. New Phil. Jour.* xlvii. 175.

[2] *Mem. Wer. Soc.* vol. ii. p. 35. Also *Proc. Roy. Soc. Edin.* vol. iii. p. 121.

shed thus separates two divergent series of striations.[1] Again, in the vale of the Slitrig, under enormous accumulations of boulder-clay, Silurian grits may be seen striated in the line of the valley. At the south end of a railway cutting, about three miles above Hawick, a beautifully-polished surface of these rocks has been exposed. The striæ run south-west and north-east, the direction of the depression in which they occur. The decomposing nature of the Silurian strata, which compose so large a portion of the southern counties of Scotland, tends to obliterate the finer traces of the general abrasion now under review. Even the hardest felspathic grits, though their component grains may long withstand the influences of the weather, are traversed by numerous joints, to which the frosts and rains find ready access. Hence the rocks are split up into blocks, and hill-sides that were once undoubtedly marked with well worn crags, are now defaced with piles and streams of angular rubbish. I have geologized over several hundred square miles of the Silurian district of the South of Scotland, and yet the instances of striations which I have met with might be reckoned on the fingers.

But though these finer markings have disappeared, the flowing outline of the hills and knolls, so characteristic of the abrasion of the Drift period, are still everywhere visible; and not only so, but there occur numerous ravines and narrow valleys, either with one or both ends cut off, running along the sides of the hills, especially where these border a principal valley. Such depressions are cut through the solid rock; they have frequently steep sides, and have every resemblance to water-courses, but they are either quite dry, or are traversed merely by the drainage of small springs issuing from the hill-side. They could not have been formed by any of the present streams, yet their general appearance is such as to impel the belief that they are nevertheless in some way or other the work of ordinary rivulets. Several good examples occur in the upper part of the vale of Tweed, as at Drummelzier and Logan. At the former locality a deep chasm has been excavated along the side of a hill rising from the southern bank of the river. This

[1] This statement is made on the authority of my brother, who has lately been carrying on the Geological Survey of this district.

chasm slopes down into the valley, and is about half-a-mile long. Its upper end stands about 370 feet above the Tweed, and bends round into a transverse glen, which here descends into the main valley. Yet it opens into this lateral glen at a great height above the streamlet. Indeed, seen from below, it looks somewhat like the truncated end of a deep railway cutting, before the erection of a lofty viaduct to carry the line across the glen. I have observed a still more impressive example on the steep hill-side that looks from the east down upon the hamlet of Manorhead, near the source of the Manor Water. These streamless defiles must indicate a former contour considerably different from that which now marks the uplands of Peeblesshire. Those which I have seen are usually near some stream, though elevated, perhaps, several hundred feet on the hill-side above it. May they not be in some cases relics of the old water-courses prior to (perhaps during) the general dressing of the rocks of the country, the present lower channels of the streams being the result of the deepening of the transverse glens by the abrading agencies of the Drift period? Some of them seem as if they had been formed when the lateral glens were dammed up so as to form lakes, and the pent-up waters escaped by cutting out channels for themselves, by which they escaped into the main river.[1]

Conformity of the Striations to the form of surface over which they run.—In the course of the preceding remarks, I have referred to several remarkable examples of the singular conformity of the striations to the inclination of the rock-surface along which they pass. As this circumstance appears wholly subversive of the iceberg hypothesis formerly noticed, I would give it additional prominence by again alluding to it. The striæ descend into the little dimples and hollows, and thus plainly indicate that the agent which produced them could not have been a rigid mass of sea-borne ice, but must have been able to mould itself upon the rocks along which it moved. Further,

[1] I know not a more fascinating, nor at the same time a more perplexing pursuit, than the study of these strange forms of surface. My old friend and colleague in the Geological Survey, Dr. Young, is at present at work among those of the Tweed, and the results of his researches will, I hope, be published in an early number of the *Memoirs of the Survey*.

the same markings are found along the sides and bottoms of narrow gullies as plainly defined as on the most exposed and open surface. Here again the grooving agent must have been able to squeeze itself through such clefts, and leave there on the rock precisely the same markings as on a bare hill-top. And not only so, but even on the face of an overhanging cliff the same finely-moulded and striated surface is visible. The Blackford Hill example is exceedingly instructive. Captain Brickenden has also described one on Dumbarton Rock, where a fissure, about ten feet wide, pointing north and south towards the valley of the Leven and the distant Ben Lomond, has its sides well striated. The west side hangs over at an angle of about 70°, and its well-marked furrows and striæ, in place of being horizontal, run nearly conformably to the declivity of the passage.[1] Lastly, the striations run up the sides and over the summits of hills. The examples cited from Loch Fyne and Bute show that sloping ground, in place of being furrowed and striated along its declivity, has been smoothed off and scored by an agent which deliberately ascended from the sea level, and after topping hills of from 500 to 800 feet in height, went down to the sea on the other side. That the agent did not originate on the hill-top, and descend on all sides to the sea, is shown by the fact that the faces of the knolls and hillocks which look down the hill to the north, are worn and rounded off, while those which look up, are rugged and angular. On the south or south-west side, on the other hand, it is the fronts that look *up* the hill which are ground down. Hence the abrading agent has moved steadily onward from the north or north-east, and so vast must have been its volume, and so resistless its impetus, that hills of 500 or 800 feet in height were little more than mere mole-hills in its line of march.

"*Cray and Tail.*"—In the basin of the Forth, and less obtrusively in other parts of the country, there is a remarkable form of hill, to which Sir James Hall gave the name of "*Cray and Tail.*" The more isolated hills are often found to present abrupt faces to the west and north-west, with more or less steep sides to the north and south, and tailing declivities to the east. They form, in fact, long ridges, each rising up gently from

[1] Brickenden, *Quart. Jour. Geol. Soc.* xi. p. 27.

the plain, increasing in height and steepness towards the west, until it terminates at its western extremity in a bold craggy eminence, in front of which usually lies a gentle depression or valley. Many good examples occur in the hills round Edinburgh; they are found also in East-Lothian in such eminences as North Berwick Law; in Linlithgowshire, Binny Craig[1] is a conspicuous illustration; and in Stirlingshire, the rock of Stirling Castle.

It is a common error to suppose that the "tail" consists merely of detritus heaped up in the eastern lee of the hill. This is by no means the case. The "tail," almost equally with the "crag," consists of solid rock. Sometimes, as in the lee of Arthur Seat, the eastern declivity has a considerable thickness of boulder-clay, or sand and gravel heaped over its surface. But, even if such superficial accumulations were removed, we should still find a tail of hard rock. One of the most familiar examples of this fact is afforded by the long declivity reaching from Edinburgh Castle down to Holyrood Palace, on which is built the "ridgy back" of the Old Town. The section at the Castle Hill shows that the steep rock on which the Castle stands is a mass of compact basalt, rising through strata of lower carboniferous age, which dip away from it to the east. In the process of cutting some deep drains down the main street, that runs along the crest of the sloping ridge, the carboniferous rocks were found for a long way east, with hardly any covering of drift or soil. It was made clear in this way, that the "tail" which slopes eastward from Edinburgh Castle is not a mere ridge of drift, but consists of sandstone, shale, and marl, dipping steadily towards the east, these strata having been cut away on the south and north sides, so as to stand up as a prominent ridge. Below the western front of the rock, there is a deep depression, which encircles both its northern and southern sides. In short, it resembles a huge pebble lying in the bed of a rivulet, with a tail of sediment pointing down the stream, and a hollow in front of it, formed by the eddy of the water. This resemblance of the form of hill called "crag-and-tail" to the ridges formed in the lee of blocks of stone in

[1] For an excellent description of Binny Craig, see Maclaren's *Geology of Fife and the Lothians*.

the bed of a stream, led to the idea, that the hills had been worn into their present outlines by strong westerly currents. It is not easy to see, however, how any current or any force of breakers could have effected such a result. A submarine current would probably have little or no effect on hard rock, and a line of breakers would depend for the progress of their devastations more on the character of the obstacle opposed to them, than on their impulse in any one direction, communicated from open sea. In what is commonly known as *marine* denudation, I suspect, the ordinary atmospheric agencies, as springs and frosts, play a far more important part than the waves. The sea, perhaps, does little more than remove the debris that falls from the cliffs, as these are shattered by the weather. Hence it seems to me highly improbable that a long bank of sandstones and shales sloping away from a hill of harder greenstone or basalt, should be the result of any form of marine denudation. Yet it is hardly possible to doubt that the trap hill has in some way acted as a buttress to the more easily wasted rocks behind, and that the whole have been worn down by some powerful agent which set from west to east.[1]

But crag-and-tail is only a part of the general abrasion of the central valley of Scotland. No one can have passed through this district from south to north without observing that the whole region is deeply furrowed in an east and west direction. Long smooth-backed ridges follow each other in endless succession, and on these we can trace every gradation of eminence, until we reach the true typical form of crag-and-tail. When it is recollected how exactly these ridges coincide with the general moulding and striation already described, it seems reasonable to ascribe the whole to the operation of the

[1] It is right to mention, that many of the quoted examples of crag-and-tail derive much of their prominence from the fact, that the strata dip to the east, and of course present to the west a natural escarpment. This did not escape the notice of Playfair, when arguing against the introduction of violent debacles to account for the phenomena of "crag-and-tail" (*Illustrations of the Huttonian Theory*, p. 408). Corstorphine Hill is a sheet of greenstone dipping in a westerly direction, and its escarpment lies towards the east. Still it cannot be denied that some of the examples of crag and-tail are not mere natural escarpments to the west, but have been produced as suggested in the text.

same great force acting steadily for a vast period in an east and west direction.[1]

Contorted and Broken Rocks under the Drift.—It is evident that unless a rock is hard enough to receive impressions, and to retain them when made, we need not expect to find on it a striated surface. Where the edges of soft shale come to the surface, no dressings are likely to occur. Yet in such cases, instead of a smoothed and grooved surface, we sometimes meet with a band of broken fragments of the underlying rocks, or with a remarkable crumpling of their strata, as if the agent which was rounding and scooping the other and harder masses could only twist up and fracture the edges of the shales. Dr. Fleming has described several examples of such broken and fragmentary strata under the boulder-clay of the vicinity of Edinburgh. In one instance "from two to three feet of angular fragments or shivers of bituminous shale rested immediately on the fixed strata of the same material. The boulder-clay rested on the shivers, and seemed to have been in motion from west to east, and at one place had squeezed a process of the shivers into its substance, so as to be above, below, and in front of the projection."[2]

A beautiful example of this kind was exposed some years ago in a quarry near Dechmont, Linlithgowshire. The rocks there laid open consisted of various black shales and thin clay iron-stones, dipping at an angle of 40° or 45°. Their edges, sharply cut off by a superincumbent layer of clay, were crumpled and bent up, as if some heavy body had moved along their edges. I have seen highly inclined shales so bent over by the slow sliding of the soil down the slope, as to appear to be dipping in a direction opposite to their real inclination. But in the case I have cited from Dechmont, this could not have happened, for the ground was comparatively level.

Again, it frequently happens that a rock is so broken along its upper surface, and so obscured by its own debris, as to remain concealed over a considerable area. I do not refer to mere surface decomposition. There is a hill of red sandstone, for instance,

[1] The general trend of the ridges and valleys in the Lothians and Fife is excellently shown on the shaded one-inch maps of the Ordnance Survey.

[2] *Lithology of Edinburgh*, p. 52.

between the ridge of Newbigging and Oggscastle, in the upper ward of Lanarkshire, so completely enveloped in its own ruin, that the rock of which it is composed can hardly anywhere be seen *in situ*. And yet numerous quarries have been opened on its long moory top, and all the walls of the neighbourhood have been built out of the angular rubbish. The blocks, where seen in any of the quarries, are enveloped in a sandy or clayey paste, in which occur a few striated fragments of felstone and Silurian grit from the hills to the south. At the north of the Carnichael burn, a few miles to the south-west of the locality last mentioned, a chocolate-coloured sandstone, belonging to the lower Devonian series, is covered with large masses, torn up from its own beds, and more or less surrounded with clay.

I associate both the surface contortions and disruption of the rocks as evidence of the operation of the same great agent which gave rise to the mouldings, groovings, and striations. What was the nature of this agent will better appear after an examination of the boulder-earth or till which occurs so universally throughout the country, and so persistently accompanies the striated rocks.

2. *Boulder Clay or Till.*[1]

The frequent association of a stiff boulder-clay with dressed surfaces of rock, and the freshness of the markings when the clay is washed from them, cannot but suggest that both clay and striations have resulted from some common and simultaneous process. Had the finely-polished surfaces been long exposed, they would have been partially, if not wholly defaced. Their perfect state of preservation is probably good evidence that no very long interval could well have elapsed between the dressing of the rocks and the deposition of the clay upon them; that, in short, these two events may be regarded as geologically contemporaneous. Probably no member of the Drift series of Scotland requires a more rigorous definition than this peculiar boulder-bearing clay. There are deposits of clay in different parts of the country, classed together as boulder-clay and resembling each other, at least, in the fact that they contain transported stones in greater

[1] These terms are used interchangeably in this paper.

or less quantity. Overlying some of the finer laminated clays and silts of Aberdeenshire, beds of a stiff boulder-bearing clay are found, and strata of a similar kind are also seen among the brick-clays of the Clyde. In these cases this boulder-bearing clay either itself contains marine shells, or is associated in such a way with stratified deposits as to show that it is truly of marine origin. So far as my observation goes, and in this I am confirmed by other observers, this undoubtedly marine clay is a fine mud with stones interspersed, sometimes in tolerable abundance, through its mass. If the stones are removed, the clay may be used for bricks, as is done extensively at Paisley and on the coast of Aberdeenshire. We can, without difficulty, conceive of the occurrence of the stones as an accident not essential to the formation of the deposit. The clay into which they seem to have been dropped is in many cases just such a clay as that of the beds above or below, save perhaps that it shows no lamination.

But this is not the character of the true boulder-clay or till. We cannot conceive of it without its boulders and pebbles. It is not merely a clay with a greater or less number of boulders scattered through it; it is rather an earth—a mixture of gritty clay, sand, gravel, and boulders, heaped together indiscriminately in constantly varying proportions. With certain exceptions to be afterwards specified, it shows no trace of stratification, and must be due to some agency different from that which produced the boulder-bearing clay associated with the well-stratified clays and sands of the Clyde and Aberdeen.

The term boulder-clay or till as a stratigraphical and not a mere lithological appellation, I would restrict to the pell-mell agglomeration of clay and boulders so well known in Scotland. This formation was first studied in the Lowlands, and it is there that it acquires its greatest and typical development. In the Highlands, and also (though to a less extent) in the uplands of the south, this boulder-clay has either been less abundantly deposited, or has suffered much from subsequent denudation. Glaciers, and the waves of the sea, as well as the rains and rivers of these misty regions, have all been at work in sweeping off the old mantle of boulder-clay. But in the broad plains and valleys of the central districts it is still preserved often in masses of great thickness. It is found along the course of almost every stream, sometimes rising into cliffs more than sixty or one hundred feet high where the characteristic features of the deposit may be studied in detail. While, therefore, there are in Scotland masses of boulder-bearing clay belonging probably to several periods in the long Ice-age, and taking their origin from the operation of different agencies, it is this thick tumultuous formation, as best seen in the lower parts of the country, that I would especially name The Boulder-Clay.[1]

This deposit is commonly believed to be a very simple one, and such I supposed it to be until I set myself sedulously to work out its structure. It is described as a mere unstratified conglomeration of boulders and gravel in a matrix of stiff clay. This is undoubtedly its prevailing character. But it also contains, as I shall show, lenticular stratified beds. In some localities it has yielded the remains of sea-shells, in others the bones of land-animals, and (as I have ascertained this year) traces of land-plants. In short, no deposit with which I am acquainted offers a greater number of perplexing problems, and in this opinion few Scottish geologists will decline to agree.[2]

Its composition.—The boulder-clay is usually hard and stiff, full of gravel and stones of every size, up to boulders of several feet in diameter. When cut through, as in quarries and railway sections, it is frequently found to possess such extreme toughness as to make its removal a matter of great labour and expense. It requires to be quarried with the heavy pick, and its larger boulders have to be blasted with gunpowder, and removed in fragments. Hence an excavation in boulder-clay is often more expensive than through some kinds of solid rock. When exposed along lines of cliff and in ravines, it may be often seen to yield to the influence of the weather, after the manner of a compact conglomerate. Huge masses become

[1] I am fully aware how difficult and indeed impossible it sometimes is in practice to distinguish between these different clays. The reasons for this similarity will probably appear as our investigation advances. I think it highly probable also that part of the pell-mell gravelly detritus in some Highland valleys (which have not been the seat of local glaciers) may be the equivalent of the boulder-clay, though the utter absence of detritus of any kind over large tracts of the Highlands, and the perfect bareness of the moulded and striated rocks, still remains as a grave difficulty.

[2] Mr. Robert Chambers truly characterizes it as a "mysterious deposit."

detached and fall headlong like crags of solid rock, and many weeks may elapse before these crumble down into mere mounds and hummocks. A fresh surface of boulder-clay commonly remains for a long while barren of vegetation, until, by degrees, the coltsfoot and thistle take root, and then a few tufts of stunted grass, which scantily relieve the cold cheerless aspect of the bare earth and stones.

This deposit, as its name imports, is commonly a clay, or at least an earth; but this is not always the case. In sandstone districts, for example, it sometimes becomes so sandy as to pass into a kind of comminuted paste of sandstone fragments. In other localities, particularly where shales and slates abound, it is a soft unctuous clay. But its common character is that of a stiff, gritty, gravelly clay or earth.

Its local character.—The colour of the boulder-clay varies in different parts of the country, and this variety, as is well known, coincides with the changes in the character of the rocks which it overlies. "The boulder-clay, in the great majority of cases," says Hugh Miller, "is, both in colour and quality, just such a clay as might be produced from the rocks on which it rests. The red sandstone rocks of Moray, Cromarty, and Ross, are covered by red boulder-clays; and a similar red boulder-clay overlies the red sandstones of Forfarshire; and I was first apprised when travelling in Banffshire, some years ago, that I had entered on the district of the Old Red, by finding the boulder-clay assuming the familiar brick-red hue. Over the pale oolites of Sutherlandshire, as at Brora and Golspie, it is of a pale yellow tint, and of a yellowish-red over the pale old red sandstones of the long flat valley known as the Howe of Fife. Again, in the middle and north-western districts of Caithness, where the paving flagstones so well known in commerce give to the prevailing rocks of the district a sombre tint of grey, the boulder clay assumes, as in the neighbourhood of Wick and Thurso, the leaden colour of the beds which it overlies; while over the coal-measures of the South of Scotland, as in East and West Lothian, and around Edinburgh, it is of a bluish-black tint, exactly the colour which might be premised from the large mixture of shale-beds, coal-seams, and trap-rocks which occurs amid the prevailing light-hued sandstones of the deposits beneath."[1]

Many additional instances might be cited of the same fact. If we journey eastward from Edinburgh, we pass first over the dull blue or leaden clays that cover the carboniferous rocks. Towards the eastern districts of Haddingtonshire, the tint changes to a bright red, and reveals where the old red sandstone has begun to set in. This hue is replaced by one of a pale bluish-grey, as we ascend into the Silurian region of the Lammermuirs. But no sooner do we reach the Berwickshire Merse than the red soil of the plain reveals once more the presence of the old red sandstone. So, too, in travelling southwards from Glasgow, we mark the black or leaden boulder-clay of the carboniferous tracts change into one of a red or almost orange tint when we reach the red sandstones of Mauchline. The same colour returns as we pass into Nithsdale, and stretches southward over the area occupied by the red sandstones of Dumfries.

This markedly local colouring is, of course, a clear indication of a corresponding variety in texture and composition. It is not unusual to speak of the boulders in the boulder-clay as *travelled-blocks* or *erratics*. This, however, is by no means their character. They consist almost entirely of the rocks of the immediate neighbourhood.[2] Thus in the gneissic and schistose tracts the pebbles and boulders in the clay are of gneiss, schist, granite, porphyry, or some of the other rocks common in metamorphic districts. Throughout the Lothians the prevailing boulders are of greenstone, basalt, sandstone, limestone, and shale—the rocks of which that part of the island is mainly composed. It is rare to find in the clay, boulders which have come more than a few miles from their parent rock. Moreover it is worthy of remark that the stones which have come from some distance are of small size, usually mere pebbles. The larger boulders in the boulder-clay are all from the rocks of the neighbourhood, and they become larger in size, less rounded

[1] *Sketch-book of Popular Geology*, p. 34. See also Cumming, *Quart. Jour. Geol. Soc.* vi. p. 10, and other authors.

[2] This local character of the boulders is well shown in the tables of percentages in the till, given on a subsequent page.

and worn, and more abundant, the nearer they approach to the parent masses from which they have been detached. The large blocks of primary rock scattered over the low grounds and hills of the central district of Scotland, do not occur in the boulder-clay, and belong, as we shall see, to a subsequent condition of things. In truth, a boulder more than four or five feet in diameter is a rarity in the boulder-clay. Here and there in the vicinity of trappean hills, blocks of greenstone and basalt may be found in the clay, measuring perhaps as much as five or six feet in diameter. But even the larger boulders usually fall short of three feet, and in the vast majority of cases the stones of the boulder-clay are mere chips and pebbles.

These stones may be described as on the whole rounded, passing into subangular, with a smaller number of angular forms. Such fresh angular fragments in the till are almost always seen to be pieces of the underlying or adjacent rocks; while the more worn stones can usually be traced to a further source.[1]

Striation of the Boulders in the Till.—The most remarkable feature in the stones of this deposit is the abundance of the striations on their surface. It is in many places scarcely possible to pick out a piece of hard greenstone, limestone, grit, etc., without finding its smoothed surface covered with fine striæ. These markings are best seen on smoothed and more or less rounded fragments of some close grained rock. On the fresh angular stones they are much less frequent. Sometimes every portion of the boulder, even its dimples and hollows, is striated, sometimes only one side, which is then usually flatter and smoother than the other sides. The striations vary from the minutest hair-lines to ruts like those of a plough or harrow. Very commonly they run over the boulder not at random, but with a remarkable persistence in the line of its long axis.[2] Oblong

[1] So far back as the year 1809, the character of the stones of the boulder-clay (or "old alluvial cover"), was accurately described by Bald, from the Clackmannan coal-field. It is, he says, "a stiff red-coloured clay, containing great numbers of small smooth stones, and large smooth boulder-stones. With these are mixed, in very large abundance, specimens of almost all the strata of the adjoining coal-field, and it is somewhat remarkable that these fragments are quite sharp at the angles, and very little worn."—*Mem. Wer. Soc.* vol. i. p. 481.

[2] Hugh Miller has a graphic account of this peculiarity of the boulders.—*Brit Assoc. Rep.* xix. 93.

rounded stones may thus be frequently seen with every part of their surface striated from end to end, and the same direction of the markings may be traced even where these occupy only one side of the stone. The striæ often cross each other, one series partially effacing an older set. This may be illustrated in almost every section of the boulder-clay. We see how the stone firmly held, as in a vice, in one position, was pushed along a surface either of hard rock or of other boulders, and thus received a polishing and striation in a given line, and then how it shifted its place, and underwent a new attrition in another direction. Thus one stone may show traces of having more than once changed its position during the process of abrasion which produced the boulder-clay. Dr. Fleming has referred to a piece of shale, on which he counted seven distinct scratched planes.

In no respect do the ruts and striæ on the stones of the till differ from those already described as marking the surface of the parent rocks. It is, therefore, evident that these markings, whether on a hill or on a boulder, are all the results of one common process. It is not less clear that the boulders are not merely abraded fragments detached from masses of rock that had been previously dressed, for the boulders are frequently striated on all sides, which could only have been effected when they were separate and independent blocks. The freshness of their markings, too, as well as that of the markings on the rock-surfaces below, indicates that they could not have been exposed to any long wear and tear before being entombed in the clay, and that, therefore, the formation of the clay and the grooving and polishing of the rocks and of the boulders, were, in all likelihood, contemporaneous events.

Unstratified Character of the Till.—The true till or boulder-clay over the greater part if not the whole of Scotland shows no trace of lamination or stratification of any kind. Nor, save with rare exceptions, are its boulders arranged in any determinate manner. They lie at all angles and at all depths, without regard to size. Large and small, angular and rounded, sandstone, limestone, greenstone, basalt, are thrown together at random. It is the most thoroughly unstratified deposit in the island. At the same time, it seems by no means improbable that the unstratified till will be found shading away horizontally into a stratified deposit formed of the same materials. The boulder-clay of Caithness is said to show some traces of stratification, and this deposit may be on the same horizon with the thoroughly unstratified till of other parts of the island. The grounds for this inference will be given on a subsequent page.

In the most tumultuous till of the central valley from the Clyde to the Forth and Tweed, beds of finely stratified material do occur. These, however, as we shall see, are sharply marked off from the stony clay above and below them, whose characteristic want of stratification they render only the more apparent. At the same time it is sometimes possible to detect in a cliff of boulder-clay traces of more than one deposition of this unstratified material. The lower part may show, for instance, a dull leaden blue tint, while the upper portion is redder in colour, and more sandy in texture. Such subdivisions, however, are quite local, and afford, so far as I have been able to observe, no ground whatever for the separation of the boulder-clay into different horizons. The boulder-clay, as we see it now, is doubtless the result of a long succession of depositions, but I do not see how these are to be distinguished, any more than the separate beds in a sandstone quarry are to be discriminated in the general geological system to which the sandstone belongs.

Its thickness and position on the ground.—The boulder-clay throughout the Lowlands, and in many valleys of the higher districts, covers the greater part of the surface. I have traced it from the sea-margin up to heights of 1500 or 1600 feet among the Peeblesshire hills, and it probably goes higher still. Along both the eastern and western shores of the island it is seen to extend beneath the sea. It probably covers the entire bed of the German Ocean, and stretches out into the Atlantic. Still, the boulder-clay, as at present developed, is only the relics of a much thicker and more continuous deposit. There seems every likelihood that this accumulation of clay and boulders once covered the greater part of the surface of the country. Hence the extent to which it has been subsequently worn away must be very great. The thickness of the clay at any particular locality does not, therefore, necessarily indicate the original depth of the deposit. In some places it has been entirely washed away, and only from the small stones and boulders left behind can its former existence be inferred. Its thickness is thus constantly varying. Sometimes it is only a few inches thick, again it increases to many feet or even yards. In some recent borings at Leith it was found to descend for somewhat more than 100 feet below the sea-level. In the Clackmannan coal-field, which is but little above the sea, Bald pierced it to a depth of 162 feet.[1] In the bed of the Avon, which divides the counties of Linlithgow and Stirling, it reaches a thickness of from 60 to 80 or even 100 feet, at a height of 200 or 300 feet above the sea-level. In the valley of the Slitrig it must be at least 100 feet thick in some places, and this at a height of fully 700 or 800 feet. Cliffs of boulder-clay 30 to 50 feet in height, are abundant along the water-courses, especially in the low grounds between the Firth of Clyde and the mouths of the Forth and Tay.

The till lies thickest in valleys and thins away over the more exposed hill-sides. This feature cannot be better seen than along the course of the Tweed and its tributaries. The bare rounded slopes of Silurian grits and shales, sometimes with rocky scarps and scars along their front, descend from the hills until they sink beneath the thick deposit of boulder-clay—easily recognisable from its vegetation—which fills up the bottom of the valley.

I have been often struck with the singular absence of the till on trappean eminences, in districts where the deposit covers almost the whole surface. A tract of sandstone, limestone, or other stratified rocks will be found thickly obscured with the clay. Yet if there chance to occur in it a mass of greenstone or basalt, we may, even from a distance, detect the presence of the igneous rock, rising often with a craggy outline, and sometimes only but a few feet, out of the surrounding drift. This nakedness of the trap-rocks is occasionally rendered peculiarly prominent where some knoll of greenstone is surrounded by higher grounds formed of sedimentary strata, but thickly mantled over with boulder-clay.

Direction of Transport of the Boulder-Clay.—The coincidence in colour and composition between the till and the rocks on which it rests, shows that this clay, whatever may have been

[1] *Mem. Wer. Soc.* i. 182.

the mode of its production, cannot have been carried from a distance, but must have been formed, on the whole, in the districts in which it occurs. It does not follow, however, that there was no transport of any kind. On the contrary, though we have abundant evidence that the main mass of the boulder-clay in the basin of the Forth, for instance, consists of the comminuted debris of the carboniferous and other rocks which form the frame-work of that district, yet we can also gather that this loose fragmentary material has moved from west to east. In the upper part of the basin of the Firth of Forth the coal-fields are covered with red boulder-clay, abounding in fragments of the rocks that lie towards the north-west, and deriving its prevalent tint from the waste of the old red sandstone which stretches up to the foot of the Highland mountains. The till produced by the attrition of the red sandstone has thus been carried eastward so as to encroach on the coal-measures. The red colour, however, speedily disappears, and is replaced by the characteristic dark leaden blue, or brownish-black hue, characteristic of the carboniferous tracts. In the boulder-clay of Stirling and Linlithgow, fragments of clay-slate and mica-schist may here and there be seen. These rocks may have come from the district of the Trosachs. Similar small boulders or pebbles also occur, but more rarely, in the till of Edinburgh and Haddington. Even where the boulders are unequivocally natives of the neighbourhood, it is sometimes possible to detect the direction in which they have been moved. Thus, as was pointed out by Mr. Maclaren, blocks of the peculiar greenstone of Corstorphine Hill, near Edinburgh, are to be found in tolerable abundance to the east of that eminence, but they do not appear to occur to the west. Dr. Fleming has also adduced satisfactory proofs of an easterly motion of the boulder-clay in the neighbourhood of Edinburgh.[1]

There is evidence, therefore, that the materials which compose the boulder-clay of the basin of the Forth have been subjected to a movement from west (or west by north) to east (or east by south.) It will be observed that this direction corresponds to that which characterizes both the minor valleys of this district, and the dressings on the surface of the rocks.

[1] See his *Lithology of Edinburgh*, pp. 52, 56, 59.

It may seem for a moment contradictory to maintain that the boulder-clay has, on the whole, been produced from the waste of the rocks on which it lies, and yet that it has likewise been subjected to a movement of transportation. This difficulty, however, immediately disappears when we examine the character of the stones in the boulder-clay, particularly near the confines of two or more distinct geological formations. We there find that perhaps sixty or seventy per cent. of the stones are fragments of the rocks underneath, while of the remainder the greater number belong to the next geological tract, and only a very few can be traced to remoter localities. By taking the relative proportions of different geological formations represented by the boulders in a section of till, we may often gather some curious and important information as to the origin of the deposit.

Mr. Smith of Jordanhill many years ago made such an examination of the boulder-clay at the west end of the great central valley. "In levelling a mass of boulder-clay near Glasgow," he says, "the workmen laid into a heap all the boulders which were too large to be lifted with the spade. This afforded me an opportunity to estimate the relative proportions of the different rocks, which I found to be as follows:—

White Sandstone and Shale,	60 per cent.
Trap,	30 ,,
Clay-Slate and Grauwackè,	10 ,,
Granite,	1 ,,

The sandstone was evidently derived from the subjacent coal-formation; the trap-boulders from the Kilpatrick Hills, which are about ten miles to the north-west, their identity being proved by the zoolitic minerals which they contained; the slate and grauwackè from hills in Dumbarton and Argyleshire about double that distance; the granite blocks must have been transported from still greater distances. Beyond the Kilpatrick Hills the trap and white sandstone boulders disappear, and are replaced by grauwackè, clay-slate, and red sandstone, while those of granite and mica-slate become numerous."[1]

In the island of Bute the boulder-clay everywhere reveals the direction in which it has moved. Over the schistose dis-

[1] *Mem. Wer. Soc.* viii. p. 55.

tricts it abounds in boulders of hard gnarled mica-schist, which must have come from the north, probably from the rugged hills between Loch Fyne and the Kyles of Bute, and onward to Loch Striven. On the red sandstone south of Rothesay the same character of boulders still prevails. Not a single block of red sandstone is to be seen on the schistose division of the island, but the boulder-clay of the sandstone district is charged with blocks of mica-schist, grauwackè, and clay-slate, which have all come from a northern source. Here again it will be seen that the direction of transport of the boulder-clay exactly coincides with the trend of the groovings and striations on the rocks below.

Similar observations might be multiplied from all parts of the country. I shall add but one other illustration, which is interesting, inasmuch as it shows a movement from south to north, or from the high ground of the Lanark and Peeblesshire uplands down into the great central valley. The Pentland Hills are prolonged by Dolphinton and Biggar to the Clyde at Tinto. This range of heights consists almost wholly of various felspathic rocks, as felstones, tuffs, and felspathic grits and conglomerates. A narrow valley separates it from the great chain of the Silurian hills, which, opposite Biggar, swell up into the mountain masses of Cardon and Culter Fell, 2500 feet above the sea. North of the felspathic ridge lies another valley in which flows the Medwin, a tributary of the Clyde. The rocks of this latter valley are chiefly red sandstones with one small outlier of carboniferous limestone. In examining the boulder-clay to the north of the Medwin, I was surprised to meet with a large number of felstone fragments. These were of a dark red or purple colour, often highly vesicular or amygdaloidal. I could identify all of them with rocks in the felspathic ridge to the south. In searching more narrowly, I likewise found several fragments of a characteristic pebbly grit, which occurs in the Silurian hills to the southward, between Culter Fell and Lamington. It thus appeared that the materials of the till in this district had moved from south to north.

In order to ascertain this with as much precision as possible, I selected three localities which exhibited good sections of the boulder-clay, and from each of them I picked out a hundred stones, varying in size from three or four inches to a foot or more in length. Two of these localities were on the Swear Burn, a northern tributary of the Medwin; the third was on the Clyde, immediately to the west of the village of Liberton. The following percentages were obtained:—

	1. Swear Burn.	2. Swear Burn.
Red and reddish-grey sandstone,	70	74
Felstone, compact or amygdaloidal,	19	18
Silurian grits,	11	3
Silurian pebbly conglomerate,	0	2
Red quartz-pebbles from conglomerate,	0	2
Carboniferous limeslone,	0	1
	100	100

	3. Banks of Clyde, near Liberton.
Felstone, compact vesicular or amygdaloidal,	43
Silurian grit and chertz schist,	18
Lower (or middle) old red grit and quartz pebbles from conglomerate,	14
Soft pale red-brown or white upper old red sandstone,	11
Felstone, compact flesh-coloured (like Tinto),	8
Greenstone and basalt,	6
	100

In the first two tables there are from seventy to seventy-four per cent. of the common reddish-grey sandstone of the district. Next in abundance come the felstones, which can only have been derived from the felspathic ridge to the south. The Silurian mountains beyond are represented in the boulder-clay by a still smaller proportion, only from five to eleven per cent. The localities on the Swear Burn are about three miles north of the chain of felstone hills, and seven from the Silurian slopes. The section on the Clyde, illustrated by the third table, lies considerably to the south-west of the others, and is distant little more than a mile northward from the prolongation of the felstone ridge. Hence the proportion of felstone fragments is large, while the number of Silurian pebbles remains as before.

I am thus particular in the details of these sections since they appear to involve questions of not a little interest in the history of the boulder-clay. There can be no doubt, I imagine, of the direction from which the materials have here been brought. Not only have we the positive evidence of the identity of the boulders with rocks that occur abundantly to the south, but there is the negative evidence to be derived from the absence of specimens from any other quarter. To the west lies a range of undulating ridges formed of dark chocolate or greenish red sandstone and conglomerate traversed by dykes of bright flesh coloured or pale yellowish grey felstone. Beyond these lie the coal-fields of the Clyde. Northward are the limestones and coals which extend from Carluke to Wilsontown. Yet in the sections of the boulder-clay on the Swear Burn there were no specimens of the sandstones, conglomerates, or felstones from the west, nor of the carboniferous rocks to the north. Moreover, the varying amount of attrition exhibited by the boulders tended in a satisfactory manner to confirm the inference of a former movement of the till here from south to north. The blocks of reddish sandstone derived from the strata underneath were commonly angular; only a few presented a well-worn outline. The fragments of felstone, which had travelled several miles from their parent rocks, were almost always rounded and smooth, and more or less marked with striations. The pieces of Silurian grit, which could not have come from a less distance than seven miles, were beautifully rounded, polished, and covered with striæ. In short, the farther the source from which the stones had come, the greater had been the attrition which they suffered.

I have already pointed out that there is evidence of a divergence of the groovings and striations from the high mountainous tracts of the south of Scotland, as well as from the more elevated regions of the Highlands. In the district between Culter Fell and the Medwin the rocks are of too decaying a nature, or are too much obscured with alluvium and drift, to afford any examples of striated surfaces. But the evidence of these boulder-clay sections seems not less conclusive as to a downward movement from the high grounds into the valleys to the north. The frequently observable coincidence between the direction of transport of the boulder-clay and the line of the dressings on the underlying rocks affords another valuable link in the chain of evidence, which serves to connect the origin of the boulder-clay with the operation of one great agency that wore down and striated the whole surface of the country.

Insertion of Boulder-clay among older Strata.—Reference has already been made to the fact that the rock on which a mass of boulder-clay rests is sometimes much broken up—large angular fragments being partially or wholly involved in the overlying till. Occasionally, however, it happens that the till is not merely inserted among the interstices of loose blocks, but has been insinuated between large parallel cakes or sheets of the underlying rocks. One remarkable instance has been recorded from the quarry of Linksfield, near Elgin,[1] where a stratum of boulder-clay is intercalated between an Old Red cornstone and a conformable group of shales belonging to the oolite. The cornstone dips gently to the south-east, and its upper surface is polished and striated in the same direction as the dip. On this dressed pavement lies a bed of boulder-clay from two to four feet thick, containing fragments of the rocks both above and below it. The surface of the clay, as well as that of the strata between which it lies, is described as having a worn and abraded appearance, with polished striæ running nearly NW and SE. Above the clay comes a conformable group of oolitic shales about forty feet thick. In the process of quarrying, the bed of boulder-clay has been penetrated for 120 yards without any symptom of its cessation, while in a transverse direction it has been observed to extend nearly 300 yards. The red colour and composition of this clay are identical with those of the ordinary boulder-clay of the neighbourhood. It is plain that the shales, therefore, are not in their original position. They must either have been forced up as a great cake, while a mass of clay and stones was introduced below them, on which they were subsequently let down; or they must have been shifted bodily, and pushed over a mass of boulder-clay. The abraded and striated appearance of the clay seems rather to indicate a forward movement of the shale.

In the till, near Cromarty, as my lamented friend Hugh Miller once informed me, a band of shale was some years ago to be seen full of lias fossils. This sheet of rock must likewise have been detached in mass, and buried in the boulder-clay.

In a section (to be afterwards described) in one of the pits of the Airdrie coal-field, I observed that the till did not merely rest upon some lower strata of sand and clay, but enveloped their broken edges, as if it had been forced among them.

I adduce these incidents as additional evidence of the nature and power of the agency by which the boulder-clay was produced.

[1] Brickenden, *Quart. Jour. Geol. Soc.* vii. p. 289.

Ancient River courses underneath the Boulder clay.—The broken and contorted or smoothed and striated appearance of the rocks covered by the till has been already noticed. But there are some features of a broader kind in the relations of this deposit to the general contour of the ground. The boulder-clay lies thickest in the valleys, and thins away over the sides and tops of the hills. These valleys, therefore, must be at least as old as the age of the boulder-clay. In the case of the main valleys, they probably existed (though not so deep or wide) long before that period; the minor hollows and defiles may, to a considerable extent, be coeval with it. Theoretically it is hardly possible to doubt that many valleys must have been produced during that prolonged and inconceivably enormous erosion which is revealed by the existence of the boulder-clay. It is difficult to discuss this question, however, merely as one of results apart from a consideration of the nature of the agency concerned in the process of abrasion. I shall therefore return to it in a subsequent part of this memoir after the nature of the abrading force has been discussed. At present I wish to direct attention to certain valleys and ravines which appear to be older, on the whole, than the till, which are or have been filled with till, and to which the rivers that probably flowed in them originally have, since the drift period, returned.

The precipitous coast-line of Berwickshire from the mouth of the Pease Burn to St. Abb's Head shows several remarkable examples of such ancient ravines. At the Menzie Cleuch, near Redheugh Shore, there is a deep defile filled with boulder-clay. This channel has evidently been the work of a small rivulet; it has steep sides, especially on the west, where the rock in places hangs over, and it has been filled to the brim with boulder-clay. A tiny streamlet is engaged in re-opening this channel by wearing down the clay, but it is still far from the end of its task. Another example, on a larger scale, is furnished by the deep sinuous gorge of the Lumsden Dean, half a mile to the east of the lonely fortalice of Fast Castle. Through highly-inclined Silurian grits and shales the stream has here excavated a curving ravine in some parts 100 feet deep, and from 300 to 400 feet wide at the top, extending from the sea-margin for three quarters of a mile inland. That this ravine is the work of a stream is sufficiently obvious. Yet in sheltered crannies of its sides and bottom patches of boulder-clay are still to be seen. The conclusion is therefore forced upon us, that this water-course existed during the period of the boulder-clay.[1]

In the Edinburgh coal-field a singular excavation beneath the till has been pierced during the working of the coals. As described by Mr. Milne-Home it appears to be a true river course, worn through the sandstones and shales of the coal-measures before the district was covered up with boulder-clay. It occurs at Niddry, and runs in a north-east direction across the strata for a distance, it is said, of fully two miles. It was 200 yards wide at one point, and little more than 100 yards at another. Its sides were shelving, and its bed filled with rolled boulders.[2] As this remarkable channel, however, lies in the middle of the coal-basin, deeply buried underneath the clay, it has never been accessible for geological investigation.

An example of much smaller dimensions, but which is open to the light of day and easily accessible, occurs on the bank of the Carmichael Burn, near the parish church of Carmichael, Lanarkshire. In a low cliff bordering the stream there is laid bare the section of a water-course about nine yards broad, bounded by walls of nearly vertical red sandstone, and overlaid with the usual stiff brown boulder-clay of the district. The bed of this water-course is filled with shingle and sand, over which lie a few inches of fine olive-coloured and reddish sand and silt, with well-defined stratification. The boulder-clay passes from the edges of the sandstone beds on the south side over the underlying sands, cutting them entirely out in its progress, until it reaches the shingle, and then the sandstone rocks that form the other wall of the channel. The shingle is precisely that of a stream, and the breadth of the channel, which is probably cut through obliquely, does not greatly differ from that in use by the present rivulet. It deserves to be remarked that in the course of this stream several patches of stratified

[1] Mr. Maclaren has described some other, but, as it seems to me, less forcible instances.—*Edin. New. Phil. Jour.* xliv. p. 181. I have an impression that Mr. Robert Chambers has somewhere referred to ancient ravines on the Berwickshire coast, but I have mislaid the reference.

[2] *Trans. Roy. Soc. Edin.* xiv.

clay, sand, and gravel occur in the till. These deposits in their composition and structure resemble those of a small stream with broad shallow pools. It is difficult to avoid believing that during the boulder-clay period a streamlet ran down this valley from Tinto to the Clyde, and that in these shingles, sands, gravels, and silts, we have traces of its existence.

I might enumerate many examples of old river valleys filled with boulder-clay and only partially re-occupied by the present rivers. One of the most remarkable which I have seen is in the well-known district of the Cartland Crags, near Lanark. The Mouse Water descending from the shady ravines of Cleghorn flows smoothly for half a mile through an old valley still choked up with boulder-clay. This valley runs on below the house of Baronald, towards Orchard-dell, but, instead of keeping this, which was probably its ancient course, prior to boulder-clay times, the river turns abruptly round in front of Baronald, and plunges into the old red sandstone, through which it has worked a dizzy ravine some 200 feet or more in depth, whose western precipices are known as the Cartland Crags. Emerging from this well-nigh twilight gorge, the river rejoins its old channel, and then, sweeping through a broad alluvial haugh, loses itself in the Clyde.[1]

Where the river Ayr issues from the fairy-like ravines of Barskimming, it enters a level alluvial plain, at the farther end of which it is bent round into a loop, by an opposing bank of boulder-clay, which lies between two walls of sandstone, and evidently fills up an old river-channel.

On the west bank of the Lyne Water, a tributary of the Tweed, at a bend about a quarter of a mile above Lynedale, a mass of stiff red till and boulders may be seen occupying a gap in the rocks, which appears to be an ancient water-course.

In these and numerous other examples it is clear that not only did the present valleys in many cases exist prior to the deposition of the boulder-clay which now fills them, but that they were occupied by rivers, of which the existing streams appear to be the lineal descendants. That these valleys suffered

[1] There are some features in the ravines of the Mouse Water and its neighbourhood exceedingly puzzling. They are at present under investigation, and I hope to describe them in a future part of the Memoirs of the Geological Survey.

greatly during the general erosion of the country at the time of the boulder-clay, is in the highest degree probable. But the occurrence in them of river deposits which have survived the deposition of the till, appears to show either that these valleys did not share in the general erosion, or, what is far more likely, that during this early period of the drift, the rivers were at least occasionally permitted to resume their old channels, and recommence their work of demolition.

I cannot but impress upon observers the importance of a careful estimate of the amount of erosion effected by streams since the age of the boulder-clay. If we are ever to obtain an approximation to the antiquity of the Drift, it is by investigations of this kind, carried on with the extremest caution, and with a determination to use only such data as are based upon actual observation. Could we obtain a measurement of the annual amount of waste produced by a stream in its channel during the lapse of a hundred years, we should advance at least one step in the determination of how many centuries may have rolled away since the stream, turned out of its ancient course by the deposition of the boulder-clay, began to excavate a new pathway for itself through solid rock. In the meantime, while we stand in the gloom of one of those profound gorges, and reflect that the chasm is not the result of primeval convulsion, but of the slow silent influences of the elements acting since the era of the boulder-clay, we learn in some degree by how vast a succession of centuries our own age is separated from the time when, after the deposition of the till, the streams began to excavate their present channels.

The true till or boulder-clay, wherever I have seen it, is thoroughly unstratified. It is now necessary, however, to describe some features of this deposit which are as yet only partially known to geologists, and which deserve a much greater share of attention than has hitherto been given to them. I shall therefore enter into greater detail in this part of the subject, as a number of the facts which I shall bring forward have not hitherto been recorded.

Stratified beds at the bottom of the Boulder-clay.—Upwards of fifty years have passed away since Mr. Bald showed that the lower part of the till sometimes rests on well-stratified sands or clays. In the Clackmannan coal-field, as mentioned on a preceding page, a cutting was made through the boulder-clay to the depth of 162 feet. "When the till," says Mr. Bald, "was cut through to this great depth, the lower six inches of it which rested on the coal-strata, was quite different from all which was above it; it appeared to have been deposited from water in the most quiescent state, as it was divided into the finest laminæ, not thicker than imperial paper; and when a thick piece was taken up these laminæ could be separated and turned over like the leaves of a book, and their tenacity and flexibility was considerable, being very much similar to fine bread-paste rolled out very thin. This was the only instance we have seen of this sort of clay."[1]

Dr. Fleming has recorded the occurrence of sand and gravel under "boulder-clay of a greyish colour," at the Bay of Nigg, near Aberdeen, and of similar materials in a like position at Redhall quarry, near Edinburgh."[2]

Below the till of the Edinburgh coal-field, beds of sand are occasionally passed through in sinking the shafts of the pits. Mr. Milne-Home, in his memoir of this district, remarks that these beds consist of fine sand and gravel, and sometimes reach a thickness of sixteen feet.[3] Dr. Fleming remarks, with justice, that there is reason to suspect the want of continuity of these beds, which consist, at places not very remote, of very dissimilar materials.[4] Mr. Smith of Jordanhill has mentioned the occasional occurrence of similar stratified sands and gravels below the till of the basin of the Clyde.[5] In a cutting on the Hawick branch of the North British Railway, about twelve miles south from Edinburgh, these strata were found to have a depth of from fifty to sixty feet or more.[6]

I am not aware of any other recorded example of the intercalation of stratified materials between the boulder-clay and the surface of the rock below, nor have I ever been so fortunate as to detect one in nature.

Stratified beds in the Boulder-clay.—If it is rare to find stratified sand and clay below the till in Scotland, it is not less so to meet with them in the heart of the deposit. Pro-

[1] *Mem. Wer. Soc.* (1809), i. 482.
[2] *Lithology of Edinburgh*, p. 51.
[3] *Trans. Roy. Soc. Edin.* xiii. 309.
[4] *Lithology of Edinburgh*, p. 54.
[5] *Researches*, p. 44.
[6] Nicol, *Quart. Jour. Geol. Soc.* v. 20.

fessor Nicol, indeed, has described certain irregular nests and lenticular laminæ of sand, sometimes curiously contorted, which were laid open in the boulder-clay during the formation of the Edinburgh and Leith Railway.[1] Mr. Jamieson refers to irregular seams of sand, often curiously contorted, in the boulder-clay of the valley of the Dee.[2] I have seen similar contorted bands of sand in the till at the viaduct of the Edinburgh and Glasgow Railway over the river Almond. Mr. Smith of Jordanhill has also noted the existence of a bed of clay, with Arctic shells in the till, near Airdrie.[3] But, with the exception of these observations, the examples which now fall to be described are, so far as I know, the first that have been recorded.

The first instance which occurred to me lay on the east side of the Slitrig Water at a bend of the stream immediately above the Crowbyres Bridge, and about a mile and a quarter from the town of Hawick. I was informed by Mr. J. H. A. Murray, Hawick, that this cliff of boulder-clay contained a layer of stones, and recollecting an incidental observation of Mr. Chambers on the occasional occurrence of such zones of boulders in the true till,[4] of which I had never been so fortunate as find an example, I twice visited the section on the Slitrig. The cliff at this locality is at least forty or fifty feet high, and consists of a stiff bluish-grey clay stuck full of boulders. The bed of stones or shingle is well seen even at a little distance, running as a horizontal band along the face of the cliff at a height of some fifteen or twenty feet above the level of the stream. On closer examination this zone proved to consist not merely of water-rolled shingle : over the lower stratum of rounded stones lay a few inches of well-stratified sand, silt, and clay, some of the layers being black and peaty with enclosed vegetable fibres in a crumbling state. The entire section of the cliff stood as under :—

	Vegetable soil.
	Boulder-clay, thirty to forty feet.
Stratified beds.	Yellowish gravelly sand.
	Peaty silt and clay.
	Fine ferruginous sand.
	Coarse shingle, two to three feet.
	Coarse, stiff boulder-clay, fifteen or twenty feet.

[1] *Quart. Jour. Geol. Soc.* v. p. 29.
[2] *Ibid.* xvi. p. 356.
[3] *Ibid.* vi. p. 386.
[4] See *Edin. New Phil. Jour.* liv. p. 256.

The lower boulder-clay contained, on the whole, larger stones than the upper. They were very generally striated, and consisted almost wholly of the hard Silurian grits and shales of the surrounding hills, with a few pieces of the igneous rocks of the district. The clay in which these blocks were thickly imbedded was stiff and compact, evidently the result of an abrasion of the Silurian rocks which compose this region. The stones in the shingle band were identical with those of the boulder-clay, save that they were more rounded and water-worn, and, so far as I could see, showed no striations. They resembled in every respect the stones now lying in the bed of the Slitrig. Indeed, if we could deflect the stream and fill up its present bed with boulder-clay, we should produce a section not unlike that shown in the cliff. The layers of sand and silt overlying the layer of shingle suggest the operation either of a river or a lake. So far as it was possible to ascertain the nature of the vegetable remains in the peaty layer, they appeared to be the rootlets of a kind of heath. The boulder-clay which rested upon these stratified beds coincided in every respect with that below them, except perhaps in having not quite so many large stones. It showed several well-stratified pieces of grit.

This section took me so wholly by surprise, that for some time I could hardly believe but that it was deceptive, that the stratified intercalation was a former and comparatively recent bed of the river, and that the overlying clay had been thrown forward by some landslip. But the most careful examination of the section failed to produce any satisfactory evidence in favour of such an explanation. There was no higher cliff of boulder-clay from which a mass could have been detached. Moreover, the fine layers of clay, silt, and sand could be followed along the whole length of the section without any trace of disturbance, such as it might be supposed would have befallen them had a whole hill-side of clay and stones slid down upon their surface. Looking at the section without reference to any theories about the origin of the beds, an unprejudiced observer could hardly doubt that the whole formed a continuous series, the oldest member being at the bottom, and the newest at the top. Though I could not disprove this order of succession, I still felt reluctant to admit the reality of a phenomenon which seemed to run counter to the familiar character of the boulder-clay.

In the same valley, however, I soon after obtained other examples of the intercalation of stratified materials in the tumultuous and unstratified till. The Border Union Railway, which runs up the Vale of the Slitrig, has made some deep cuttings through the clay. These are now earthed over, and sown with grass, but Mr. Harrison, the resident engineer of the line, kindly accompanied me along the cuttings, and had part of them re-opened for my inspection. A short distance above the Crowbyres Bridge, in one of these excavations through the boulder-clay, there occurred a bed of light-coloured plastic clay without stones. Owing to the earthing of the side of the cutting, I could not ascertain the extent of this clay. But there could be no doubt that it was a bed lying in the true till. Mr. Harrison informed me that it appeared to be quite local, as it died out immediately to the southward.

Again, some miles farther up the same valley, a little to the north of Shankend, in another deep excavation through the till, the workmen came upon a bed of sand. This, when cleared out afresh, I found to rest under fully forty feet of the ordinary stiff boulder-clay, at a height of more than forty feet above the river. It was fine-grained, of a reddish colour, and was associated with some finely laminated clay. So loose was its cohesion that a wall had to be built over it to keep it from being blown away by the wind. Two miles higher up the valley, another similar sand-bed occurred in a like position in the clay.

The next section which occurred was at Garpal, in Ayrshire, where the Whitehaugh Water falls into the river Ayr. The east bank of the stream close to the lonely road from Sorn to Muirkirk, consists of a group of well-stratified sands and clays, surmounted by a few feet of boulder-clay. The stratified beds yielded me no organic remains, but they deserve a more lengthened search than I was able to give them. The boulder-clay towards the bottom, where it rested on a sand-bed, showed an indistinct horizontal arrangement of its stones. A large boulder, with a striated surface, projected from the face of the bed. The amount of detritus lying along the margin of the stream prevented me from ascertaining on what foundation these strata rested. It was probably boulder-clay.

On the banks of Carmichael Water, Lanarkshire, close to the parish church of Carmichael, there is a cliff about twenty feet high, consisting of stiff brown boulder-clay. It is remarkable for containing a distinct layer of brown or olive-coloured stratified clay, which may be traced, dipping down the valley at an angle of 5°, for a distance of twenty yards, until it is obscured by grassy slopes. This layer of clay varies from less than an inch to four or five inches in thickness. It contains a few small rounded stones with thin laminæ of sand, and in one part a small lenticular patch of pebbly clay. The boulder-clay which underlies this stratified intercalation contains many well-polished and scratched stones, few of them larger than a good sized turnip, and in most cases a great deal smaller. Its upper surface, on which the stratum of sand and clay rests, presents a remarkably even line, and shows a considerable number of rounded pebbles among the angular and striated ones. These stones, for an inch or so downwards, are arranged more or less horizontally, as if some agent had partially re-assorted them before the deposition of the overlying stratified layer. With this exceptional part both the lower and the upper boulder-clay are thoroughly unstratified.

About a mile higher up the same stream another cliff displays a still more remarkable series of beds of gravel, sand, and clay in the true till. These strata are quite local even in the short section laid open along the cliff, and they are not seen in any other part of the neighbourhood. They are remarkable for the extreme minuteness of many of their layers, and for the rapidity with which the sand and gravel seams succeed each other. One layer is sometimes seen to be abruptly cut away and its place occupied by the next in order. This was especially remarked in the case of a stratum of dull red sand. A narrow trough with somewhat steep sides had been excavated in this sand and then filled with fine gravel, above which the constant alternation of beds went on as before. In another part of the section a thin seam of peaty matter was observed to run for a few inches along the bottom of a bed of clay and then disappear, while in a band of finely laminated clay, with thin sandy partings, occasional fragments of mouldering wood were found. One of the beds of this stratified series is a coarse shingle, where the interstices between the stones are occupied by fine clay and sand. On the whole the strata have a dip towards the valley; at one place the angle is as much as 10°. They more resemble the intermittent sediments of a stream than any other form of aqueous deposit. They appear to have accumulated in a hollow of the older boulder-clay on which they are seen to lie, and afterwards to have been covered over by a new inroad of the same tumultuous deposit which is now found to cover them.

But by far the most remarkable examples of intercalated strata in the boulder-clay which have yet come under my observation occur in some of the pit workings of the coal-field of Airdrie. Mr. Smith has recorded the discovery, on two occasions, of Arctic shells from the Drift of this neighbourhood, first in the clay of a brick-work about 350 feet above the sea, and afterwards in a clay which lay in the true till at a height of 510 feet.[1] Being myself anxious to compare this section with some of those I have just described, I visited the district, and enjoyed the advantage of having as guide Mr. James Russell, the fortunate finder of the shells at the higher locality.

The brick-work from which the first series of shells was obtained is now filled up and abandoned. No section of the clay is visible, so that the relations of the deposit to the other members of the Drift series cannot be ascertained. The place where Mr. Russell found the second group of shells is on the crest of a ridge, which, rising high above the surrounding country, commands an extensive view across the lower part of the basin of the Clyde to the Ochil, Kilpatrick, and Gleniffer Hills, beyond which, to the west, are faintly seen the peaks of Arran, and northward the group of mountains that rise round the lakes of the Trosachs. On the water-shed of this high-lying ridge, a well was sunk some years ago, and while the excavations were in progress the shells were found. When a thickness of about fourteen feet of surface soil and stiff hard blue till had been passed through, a stratum of fine reddish brick-clay was

[1] See his *Researches*, pp. 17, 141.

reached. This clay contained no stones, but was full of shells. It rested on a hard red stony till, which was here about twenty-four feet thick, and lay directly on the carboniferous strata of the district. The brick-clay at its thickest part measured two feet one inch in depth, but thinned away rapidly on every side, so as to allow the upper and lower till to come together. From a number of additional wells, sunk on purpose, Mr. Russell ascertained that the clay lay in a gentle hollow of the under-most till, and that this hollow measured about nineteen feet long by about five feet broad. Pits which were dug beyond the boundary of this little trough showed a great depth of the usual till, but without a trace of brick-clay. The shells consisted entirely, I believe, of *Tellina proxima*. Usually the specimens were broken, but a good many were taken out entire with both valves together. This locality was computed by Mr. Smith to be 510 feet above the level of the sea, and is the highest in Scotland from which shells belonging to the Drift have yet been obtained.

Mr. Russell informed me further that a series of sand-beds is at present extensively mined underneath the boulder-clay to supply the iron-furnaces with sand for their casting-moulds. From the numerous bores and pits which have been put down, it appears that these sand-beds lie in a long trough, about half or three quarters of a mile in breadth, formed by a depression of the coal-strata between two large faults, one of which has a throw of a hundred fathoms. Even on the surface of the ground, notwithstanding the thick covering of drift, the outline of this ancient basin can be distinctly traced by the line of sloping banks which form its margin. The opportunity of exploring several acres of the under surface of the boulder-clay is one which certainly does not often fall to the lot of the geologist; it was, therefore, with no little eagerness that I availed myself of the courteous proposal of my guide to descend the pit whence the sand is taken, and there examine the strata in detail. This pit, called No. 3 Chapelhall, is situated on the south-west side of the basin; its depth is 120 feet, and its galleries are driven in the sand-beds towards the north-east or deepest part of the trough. It does not reach the solid rock, the shaft and all the interlacing road-ways being cut entirely through masses of drift.

For a depth of 114 feet the shaft was sunk through a stiff hard stony till. The enclosed stones, I observed, in one or two cases, to be scratched, but the exposures of this clay in the pit are few, and in the flickering light of a lamp it was somewhat difficult to detect fine markings on the unwashed surface of the boulders. Nests of sand of extremely limited extent are of frequent occurrence in this clay. I noticed one or two of a few inches in thickness near the bottom of the deposit, but I was informed that higher up they were found, though rarely, to reach a depth of three feet. They lie in irregular hollows of the till, and are often separated by rough hummocky masses of it. The stratification of the sand is usually well shown, sometimes conforming to the sides of the enclosing basin, sometimes lying against them, and, in some cases, according to Mr. Russell, crumpled and distorted.

Below this till lies a group of finely-stratified sands and clays, varying in thickness up to twenty or thirty feet. It is through this group of strata that the galleries are driven. The upper part of the series, throughout most of the workings, consists of a dark brown laminated clay (or "gutta-percha" clay as one of the miners aptly called it), occasionally with a few rounded pebbles. It is full of joints and slickensided surfaces, as if it had been subjected to great pressure. As it forms the roof of the sand-bed for which the mine is worked, its structure can only be partially seen, since the miners never cut farther into it than is necessary for the removal of the sand and the clearing out of roadways. It is said sometimes to attain an extreme thickness of twenty feet, but in other parts it disappears altogether, and the overlying till comes to rest directly on the sand. I saw no junction of the till with this laminated clay, neither could I see or hear of any organic relic in the latter deposit.

The sand likewise varies greatly in thickness. From a depth of six or eight feet it rapidly diminishes to three or four, and in one part of the workings it disappears altogether, being then cut out by the overlying boulder-clay. Pure sand is by no means the entire constituent of this deposit. It contains endless lenticular laminations of extremely fine olive and pale drab-coloured clay, from the thinness of a sheet of paper up to beds a foot or more in depth. It is hardly possible to convey an adequate idea of the minuteness of the alternation and interlacing of these sand and clay seams. They are full of false bedding, the different layers being marked by a succession of darker and lighter materials. In the clay these alternations are as fine as the lines of a woodcut. Indeed, when one of the miners pared away, with a sharp knife, a clean surface of one of the clay-bands, the sectional view laid open rather resembled a reduced diagram or even a photograph of a great cliff of false-bedded, jointed, and faulted strata, than the actual occurrence of these structural features in nature. In the sand, pieces of coal are not unfrequent; one or two which I saw measured eight or ten inches across and two or three inches in thickness. Pebbles of quartz, sandstone, and greenstone likewise occur both in the sand and also, but more rarely, in some of the clay-bands. Layers of peat have been from time to time met with in these thin clays, likewise decaying twigs and branches. None were visible at the time of my examination, but Mr. Russell assured me of their occurrence, he having himself had some of the branches in his possession.[1]

Where the upper or "gutta-percha" clay thins away, and the overlying till comes to rest directly on the sands, an opportunity is occasionally afforded of examining the junction of the two latter deposits. The under surface of the till is extremely irregular. After continuing for a while even and conformable to the strata on which it lies, it is seen to descend abruptly, cutting out the sand and clay beds, or filling up a hollow in them, and reascending to a level perhaps considerably above its previous one. The line of demarcation between the coarse unstratified till and the finely laminated clays and sands is always sharply defined. There is no passage of the one series into the other. The finger may be placed upon the junction so that one half shall press on the unstratified gritty till, and the other on the fine laminated clay or sand. The actual contact of these two kinds of deposit seemed to be a matter of special import-

[1] Since this was written and while the paper is passing through the press, I have received from Mr. Russell specimens of some of the thin peaty layers. Though much decayed, the vegetable fibres are still distinct, and the substance burns with a dull lambent flame when put into the fire.

ance, and I therefore examined every instance which could be seen. At the end of one of the galleries the miners had been brought to a stand by a sudden descent of the till, whereby the sand, as far down at least as the level of the roadway, was completely cut off. This section, not having yet been boarded up, was better seen, and occupied a larger area than any other in the pit. It is represented in the subjoined figure. The

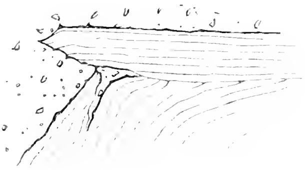

FIG. 2.—Boulder-clay enveloping stratified beds, in a pit working at Chapelhall, Airdrie.

layers of sand and clay were arranged differently in the upper and under parts of the section. A lower group of beds dipped steeply towards the boulder-clay, while their ends were overlaid by a higher and nearly horizontal series. The greater inclination of the lower beds has thus probably nothing to do with the deposition of the till, but seems rather to belong to the original false-bedding of these strata. The till first overlies the upper series in a tolerably even line, then bending round their ends so as to underlie them, it sends a vein for a few inches between them and the edges of the inclined strata, and then descends along the steep surface of the latter. This vein of till, after for a short space separating the flat from the tilted beds, goes down between two of the latter series and dies away. It thus forms a kind of wedge between which and the main mass of till a fragment of the stratified beds is dislocated so as to be almost wholly imbedded in the till. On the opposite side of the cutting, the inclination of the lower strata is not so steep, and their edges are there obliquely truncated by the till. Along the roof it appeared as if the till had been to some extent injected between and among the layers of clay and sand which were there short and irregular.

In other sections the strata showed no trace of any disturbance, but were covered conformably by the usual boulder clay. From the statement of the miner who took me over the pit, however, it would appear that the dislocation just described is by no means so great as others which have been seen in the workings. He told me that immediately under the till the beds of clay and sand are sometimes folded over upon each other, like a flattened form of the letter S, after which they continue regular as before.

The series of stratified deposits is underlaid by a lower till which, at the bottom of the pit, has a thickness of twenty-four feet. In another pit it is thirty feet thick; but it is sometimes absent altogether so as to leave the sand beds resting directly on the sandstones and shales of the coal-measures. This till I saw only at one part of the workings. There it was a stiff, sandy clay or earth, full of angular fragments of the common sandstones of the district. A few pieces of greenstone occurred among the boulders, all of which were of small size. Neither in the lower nor the upper till did I observe any single boulder of larger dimensions than a good-sized turnip, while the majority were mere pebbles. This floor of till on which the sand bed rests appears, from the descriptions given me, to be as hummocky and uneven as that of the roof, but there was not the same opportunity of examining it.

About a quarter of a mile to the north there is an ironstone pit sixty feet in depth, accessible by a flight of ladders. In driving a trial mine in this pit the workmen, at the time of my visit, had come upon an unexpected mass of gravelly clay and sand by which the ironstone and its overlying strata were abruptly cut off. This pit, it may be remarked, lies beyond the north-eastern margin of the ancient basin just described, and at a considerably higher level. The gravelly clay and other deposits were supposed by the miners to be those of an old river-course. As there could at least be no doubt that they lay below a depth of fifty or sixty feet of true boulder-clay, I took the opportunity of examining them in the pit. The ironstone here worked is the famous Mushett's Black Band,—the oldest and best of all the black band ironstones of commerce, now unhappily almost exhausted. At the end of the trial mine the ironstone, with its accompanying coal and fire-clay, were cut off at an angle of about 20° by a stiff dark-coloured earth, stuck full of angular pieces of white sandstone, coal, and shale, with rounded pebbles of greenstone, basalt, quartz, etc. Above this came an interlacing series of fine sand and clay beds, exactly resembling in colour, texture, and minuteness of subdivision, those already described as underlying the boulder-clay in No. 3 pit. These strata dipped gently away from the carboniferous beds, and had been cut into in another part of the workings. From a survey made by Mr. Russell's brother, the overseer of the pit, it appeared that the edge of these beds ran in a line which pointed N 40° E, or nearly north-east and south-west. To the east of the shaft, at a distance of three or four hundred feet, the North Calder Water has scooped out of the carboniferous strata a deep ravine, on the west side of which the ironstone, with its overlying strata, may be seen cropping out at nearly the same level as in the pit. Here the rocks are overlaid by boulder-clay, the intervening stratified deposits having disappeared. After examining the interior of the pit, and going over the surface with the overseer, who had staked off, on the fields above, the direction followed by the edge of the gravelly sand and clay in the pit-workings below, I could not doubt that there lay here, under fifty or sixty feet of boulder-clay, a channel excavated in the carboniferous rocks, eighty or a hundred yards broad, and not less, but probably more, than twenty-four feet deep, running in a north-easterly and south-westerly direction, and filled up with deposits, which, so far as then explored, were identical with those intercalated in the till in the ancient basin of Chapelhall. Standing on the rising ground occupied by the ironstone pit, and looking towards the south-west, the observer could still trace the outline of that basin lying immediately in front of the line which is followed by the channel just described. If this channel should go on for but a furlong or two farther (and from its breadth and depth this will probably be found to be the case), it must descend into the basin. Whether it is to be regarded as the track of an old river-course, perhaps a former bed of the Calder Water, or as an inlet running off from the deeper hollow in front of it, may possibly be ascertained in the course of the mining operations.

This example of a channel older than at least a part of the boulder-clay is not the only one in the neighbourhood. Mr. Russell informed me that another of the same kind had been traced in some of the pit-workings about a mile farther to the north-west. In this case also the direction was from north-east to south-west, or down towards the old basin of Chapelhall.

It is clear that whatever may be the true explanation of these channels and basins, they unquestionably belong to the period of the boulder-clay. The Chapelhall basin lies, indeed, in a hollow of the carboniferous rocks, but its stratified sands and clays rest on an irregular floor of true till. The old channel near the banks of the Calder is likewise scooped out of sandstones and shales, but it has a coating of boulder-clay, on which its finely-laminated sands and clays repose, as if the channel itself had once been filled with boulder-clay, which was re-excavated to allow of the deposition of the stratified deposits. In all cases a thick mantle of coarse tumultuous boulder-clay buries the whole.

In a cutting on the line of railway from Edinburgh to Leith, a section not unlike some of those just noticed was laid open.[1] A hollow in the boulder-clay five or six feet wide, and three or four feet deep, was filled with gravel and sand. These deposits, as well as the form of the hollow, closely resembled those of a small rivulet. A browner and more sandy clay covered this hollow, and extended over the lower till. Here it is also evident that the scooping out of this channel belongs to the era of the boulder-clay. It must have been effected during a pause in the deposition of the clay, when a run of water could find its way along the inequalities of the surface of the clay. This pause must have been of sufficient duration to enable the runnel to excavate a capacious channel for itself, and leave in it a quantity of sand and shingle. We can scarcely doubt that when this process was going on, the ground must have been a land-surface, and could not have been under the sea. And lastly, we see from the upper boulder clay that the old conditions returned, the water-course was choked up, and another mass of chaotic boulder-clay was tumbled down upon the face

[1] Described by Professor Nicol, *Quart. Jour. Geol. Soc.* vol. v. p. 20.

of the country. This leads to the consideration of another phenomenon, which may possibly indicate that the boulder-clay is not the result of one great catastrophe, but of slow and silent, yet mighty forces acting, sometimes with long pauses, throughout a vast cycle of time.

Striated Pavements of the Boulder-clay.—Although the striation on the stones and boulders of this deposit must, in almost every instance, have been produced before these became finally fixed in the clay, there nevertheless exists a curious kind of evidence, by which we learn that either during or subsequent to the formation of the boulder-clay, the boulders that had been imbedded in the clay were subjected to a process of abrasion and striation, similar to that which had previously been undergone by the solid rock below. There are, in short, surfaces, or "pavements," as Hugh Miller called them, apparently in the mass of the boulder-clay, where all the prominent boulders have not only their original and independent striæ, but where they have subsequently suffered a new striation, which is parallel and persistent across them all.

The earliest recorded observations which I have found on this subject, are by my venerated friend, Mr. Charles Maclaren.[1] In examining a cutting through boulder-clay on the old railway from Edinburgh to Dalkeith, he found that "there was a certain correspondence in the direction of the scratches and groovings on the large stones. In the diluvium (*i.e.*, boulder-clay) at Whitehill, it was about one point north of east; at Glenesk and Dalhousie Mains, the bearing varied fron NE to NNE." Mr. Milne-Home directed attention to a similar excavation on the line of the Edinburgh and Newhaven Railway, where the general line of scratches on the boulders, as those lay in the clay, was west-half-north by compass.[2] He also referred to some remarkable examples of the same phenomenon on the shores of the Firth of Forth between Leith and Fisherrow. There, over spaces of many square yards together, all the more prominent boulders have their flat upper surfaces striated in one prevailing line from WSW to ENE, which it will be remembered is a common direction of the dressings on the rocks

[1] *Geology of Fife and the Lothians*, p. 213
[2] *Trans. Roy. Soc. Edin.* vol. xiv. p. 310.

of this district.[1] Many miles farther to the east, at Thorntonloch between Dunbar and Cockburnspath, I found another example, where along the beach, for a space of thirty or forty square yards, numbers of large blocks of limestone with flattened upper sides, may be seen imbedded in a stiff red clay, and all striated in one direction, W 10° N to E 10° S. These striæ are remarkably distinct, but there are also traces of the usual older and independent striations.

On the west coast similar facts have been observed by Mr. Smith,[2] and Mr. Maclaren.[3] On the shores of the Gareloch large boulders half buried in the till are seen to be striated along the upper side in one uniform direction. This direction is from NNW to SSE, that is, parallel to the line of the loch, and also to the line of the striations on the rocks of the side of the valley.[4]

On the shores of the Solway, about a mile south from Carsethorn, I lately detected another instance. A number of blocks of hard grey sandstone and granite, imbedded irregularly in the boulder-clay, had their worn and flattened upper sides covered with a set of parallel striations running from 10° N to 15° E, that is, nearly along the line of the coast at this point, or away from the high grounds of Criffel.

The frequent occurrence of these striated pavements along the sea-margin is perhaps only an accident. We must remember that they cannot be seen except along a *horizontal* section of the boulder-clay. Sections of this kind are rarely seen in the interior of the country; they are more common along the sea-margin. Hence a horizontal surface of boulder-clay seldom meets the eye of a geologist, save where it has been laid bare by the waves. The sections on the railroads from Edinburgh to Newhaven and Dalkeith, however, show that the lines of uniformly dressed boulders are not confined to the sea level, but might be oftener seen in the interior, if there were greater facilities afforded for finding them. At the same time, it is much to be desired, that an early opportunity may

[1] See Chambers' *Edin. New Phil. Jour.* vol. liv. p. 271.
[2] See his *Researches in Newer Pliocene Geology*, p. 129.
[3] *Edin. New Phil. Jour.* for April 1855.
[4] See *ante*, p. 21.

occur of examining minutely the character of the till, which, according to both Mr. Maclaren and Mr. Milne-Home, has been found overlying these striated pavements. The attention of these accurate observers not having been specially directed to the subject, it is possible that this upper clay may have differed from the true till. I do not wish to state positively, therefore, that these pavements actually occur down in the heart of the boulder clay. The instances which have been observed along the shore have not had any boulder-clay clearly overlying them. It is possible, that the second striation of the boulders may be due to the second era of the Drift, viz., that of floating ice, instead of the first part of the period, which was remarkable, as we shall see, for its development of land ice.

Fossils of the Boulder-clay.—The extreme paucity of organic remains in this deposit has always been one of its most perplexing features. The matrix of the boulder clay is not of a kind inimical to the preservation either of animal or vegetable forms, for the few fossils which have been found have occurred in an excellent state of keeping. Had the bones or shells of animals, therefore, or the leaves and stems of plants, ever existed abundantly in the boulder-clay, they would assuredly be found abundantly still. The absence of such forms, by depriving geologists of the distinctive tests of habitat which organic remains usually furnish, has unquestionably been one powerful source of the variety of conjectures which have been hazarded as to the origin of this deposit.

The earliest recorded discovery of organic remains in the Scottish boulder-clay took place in the beginning of the year 1817.[1] When the till covering the sandstone at the quarry of

[1] It is likely, however, that bones of some of the large mammals of the Drift had been found long before the present century, though no record remains of their discovery. I cannot but agree with Hugh Miller in regarding the following quaint passage of old Bellenden as probably descriptive of some elephant remains that had occurred in digging into the Drift of the northern counties:—"In Murray land," he says, "is the Kirk of Pette, quhare the banis of Litill Johne remainis, in gret admiration of pepill. He hes bene fourtene fut of hicht, with square membris effering thairto. Vi yeris afore the coming of this werk to licht, we saw his hanche bane, als mekill as the haill bane of ane man; for we schot our arme in the mouth thairoff: be quhilk apperis how strang and square pepill grew in our region, afore they wer effeminat with lust and intemperance of mouth."—Bellenden's *Boece, Edit. Edin.* 1821, vol. i. p. xxxiv.

Greenhill, in the parish of Kilmaurs, Ayrshire, had been partially removed, there were found, at a depth of 17½ feet from the surface, two elephant tusks. One of these was so much decayed that it could not be removed. The other measured 3 feet 5½ inches in length, and about 13½ inches in circumference, and weighed 20½ pounds. The matrix in which these remains were found was a clay which, around the bones, changed from its usual light brown colour into a dark brown, with a most offensive smell when turned over. The tusks lay in a horizontal position, with several small bones near them.[1]

Other elephant remains have subsequently been found in the same neighbourhood. My friend Dr. Scouler informs me that he visited the quarry in company with the late Dr. Couper of Glasgow. "The remains of four elephants and a half, in the shape of nine tusks," had been obtained previous to his visit, and he himself picked up from the clay-heaps a small fragment of a molar. This clay, he assures me, was the true boulder-bearing till.[2]

The second example on record, however, was that so well described by Mr. Bald to the Wernerian Society. It occurred in the summer of 1820, during the excavation of the line of the Union Canal between Edinburgh and Falkirk. A large mass of boulder-clay having been undermined, fell into the cutting, and amongst the earth was found a tusk which measured 39

[1] Mr. Bald, from whose narrative the above particulars are taken, adds, "several marine shells were found amongst the dark-coloured earth."—*Mem. Wer. Soc.* iv. 64. He does not name the species, and the statement as it stands is, I fear, too vague to be of much geological value. Dr. Scouler, who subsequently visited the Kilmaurs quarry, assures me that he saw no shells. That shells were found, however, there is no reason to doubt, but as their nature appears to have been decided only by Lord Eglinton's factor, their habitat must, I fear, remain a disputed point. It will be seen that, according to the theory of the boulder-clay proposed in the subsequent pages, the marine character of the shells would be perfectly intelligible.

[2] In the *Edin. Phil. Journal* for 1825, I find a reference to the discovery of elephant remains in the same neighbourhood in the month of March of that year, and they are further alluded to in the reports of the Wernerian Society for April 2, as having been described by Professor Jamieson. I believe that all these discoveries refer to the same quarry, namely, that of Greenhill, on the banks of the Carmel Water. Dr. Scouler, at the time of his visit, which was upwards of twenty years ago, found, as stated above, that nine tusks had been obtained in all—a large number, considering the great rarity of organic remains in the till. It is singular, however, that no fragments of the larger bones have been met with.

inches in length, and weighed $25\frac{3}{4}$ lb. avoirdupois. It appeared that this organism lay about 15 or 20 feet from the surface, imbedded in the heart of the stiff boulder-clay. Such was its state of preservation that one of the workmen, conceiving it to be of some value, sold it to an ivory-turner for £2. It was fortunately rescued, but not before it had been sawn into three pieces, one of which was in the process of being converted into chess-men.[1]

At Chapelhall, near Airdrie, the bone of an elephant was found at a height of 350 feet above the sea in laminated sand underlying till.[2] This, I believe, was an elephant remain mentioned to me by Mr. Russell. The spot which he pointed out as that from which it was taken, was a hollow of the till filled with sandy deposits. I saw no till overlying the sand, but the ground has been so altered in the course of the mining operations, that it is impossible to ascertain its original condition.

Among the animals inhabiting Scotland during the Drift period, the reindeer appears to have been one. Two instances are on record of the occurrence of its antlers in Scottish deposits,[3] one in the silt forming the bed of the Clyde, the other in some drift beds in Dunbartonshire. The latter is that which is specially of interest in the present inquiry. The horn occurred in the basin of the Endrick at a point in the parish of Kilmaronock, nearly a mile from the river, and about four miles from Loch Lomond, into which the Endrick falls. The section in which it lay consisted first of the vegetable mould, then of a stiff clay twelve feet thick, containing a large quantity of stones. Underneath was a bed of blue clay, about seven feet thick, at the lower part of which, close upon the underlying sandstone, the antler was found, and near it a number of marine shells. These re-

[1] Bald, *Mem. Wer. Soc.* iv. 58. He did not actually take it out of the clay, but, after a careful scrutiny of the locality, he came to the conclusion that it must have been imbedded in that deposit.

[2] Craig, *Proc. Geol. Soc.* iii. 415. See another instance, Bryce, *Geol. Arran*, p. 9.

[3] Dr. Hibbert, indeed, has endeavoured to show (*Edin. Journal of Science*, vol. v. p. 50) that wild reindeer were hunted by Norwegian chiefs in Caithness down to the twelfth century. The occurrence of the antler described by Dr. Scouler in the silt of the Clyde proves, I think, that the animal may have survived in Scotland far down into the human period.—See *Edin. New Phil. Jour.* vol. lii. p. 135.

mains were obtained in a cutting of the Forth and Clyde Junction Railway, and were estimated to be from 100 to 103 feet above the sea-level.[1] The shells consisted of *Cyprina Islandica*, *Astarte elliptica*, *Astarte compressa*, *Fusus antiquus*, *Littorina littorea*, and the shelly base of a species of Balanus. The horn was examined by Professor Owen, and pronounced by him to be the antler of a young or female reindeer of the existing species.

Dr. Scouler has recently examined some antlers, which, along with an elephant tusk, were placed by the late Dr. Couper in the Hunterian Museum of Glasgow, the whole having been found in the till at the quarry near Kilmaurs. He informs me that they are unquestionably the horns of reindeer. It is singular that in this little Ayrshire valley, within the compass of a few yards, there should occur a greater number of mammalian remains than have been obtained from the Drift of all the rest of Scotland, and that among these there should be well-preserved relics of the only two mammals which have yet been ascertained beyond a doubt to have inhabited Scotland during the Drift period.

In the *Statistical Account of Scotland* and in the *Memoirs of the Wernerian Society* there are allusions to the discovery of the horns of the elk and the rhinoceros in superficial accumulations. But these do not appear to have been ever authenticated. Indeed, I believe the rhinoceros bones proved, in some cases at least, to be the cores of the horns of a bull, from which the outer sheath had mouldered away.

These instances of mammalian remains, along with those noted in the Appendix, are all which I have been able to discover. In connexion with them reference may again be made to the beds of peat, and the rootlets and branches of trees, which I have described as occasionally observable in the boulder-clay. These remains have not yet been botanically examined. In peaty layers which I have myself had an opportunity of seeing, the vege-

[1] See an account of these remains by Dr. J. A. Smith, *Edin. New Jour.* New Series, vol. vi. p. 105. This instance of the discovery of reindeer bones ought, probably, in strictness to be taken along with the fossils of the marine parts of the Drift. I have inserted it here since, there being no proof that it does not belong to the boulder-clay, it comes in more conveniently along with the other mammalian remains of the Drift, and since Dr. Scouler has recognised the occurrence of reindeer horns, along with the elephant tusks, at Kilmaurs.

table remains have always been so completely decomposed as to be specifically undeterminable. In one or two cases I recognised the fibrous rootlets of, apparently, a heath, which, however, mouldered away in the hand. The branches found in the pits at Chapelhall have, unfortunately, been either mislaid or lost, but as the miners have had their attention drawn to the subject, it is hoped that, should any further specimens occur, they will be preserved. In the meantime, we cannot doubt that these vegetable remains present us with traces of a land surface of the boulder-clay period. The beds of peat probably grew where they are still found, either along the bed of a shallow lake or the stiller reaches of a stream. There they were buried under a deep mass of boulder-clay, in the upper part of which were found the elephant bones of Chapelhall.

It is one of the peculiarities of the boulder-clay that this deposit, though its scanty fossil contents are chiefly those of the land, contains also, in some localities, marine organisms. The beds of fine clay containing *Tellina proxima* at Chapelhall form one example, and others may occur in different parts of the country. Mr. Smith of Jordanhill mentions that he found on one occasion sea shells imbedded in the till, much broken and deprived of their colour.[1] In his list of the mollusca of the Drift, he names *Balanus Udderallensis* and *Cyprina Islandica*, as having been detected by him in this deposit.[2] But the most remarkable illustration of the occurrence of marine organisms in what appears to be the equivalent of the boulder-clay of other districts, occurs in Caithness.[3] Throughout that county, according to Mr. Peach, the till is a hard, stiff stony clay, almost everywhere capable of being made into bricks, and commonly fossiliferous. Some of the shells still retain their epidermis, but Mr. Peach has never found a pair of united valves. Almost all the stones, he says, and even the fossils, are more or less worn, polished, and striated.

Over by far the greater part of Scotland the fossils of the boulder-clay, though few in number, are terrestrial, and their evidence, so far as it goes, points thus to an ancient land surface. The occurrence, however, of both terrestrial and marine forms *in situ* in this deposit, when I had fully

[1] *Researches*, p. 10. [2] *Op. cit.* 48, 49. [3] See List of fossils in Appendix.

established the fact, proved for a time an insuperable difficulty. Yet it seems to me that by the hypothesis suggested in the next section of this memoir, the problem may be satisfactorily solved.

3. *Theory of the Origin of the Striations and the Boulder-Clay.*

In the foregoing part of this memoir, while describing the character of the phenomena of the older part of the Drift, I have endeavoured to avoid, as far as possible, the statement of any theory as to the mode in which these phenomena have originated. It appeared most advantageous to arrange the various facts in their natural order and connexion, that they might, in a manner, tell their own story. This, I think, they will be found to do.

At the present day it seems altogether superfluous to raise the ghosts of the old floods and debacles, which, after playing so active a part in the early history of geology, have now for a good many years been quietly consigned to oblivion. Few now seriously hold the belief, that the phenomena of the Drift are due to a vast cataclysmal deluge, or to any number of deluges, how enormous soever in power and long continued in operation. It is confessed, that the moulding and grooving of the rocks, and the accumulation of the boulder-clay, have been produced by the agency of ice. No other agent known in nature could give rise to the long, straight striæ, and the moulded outlines of the country, or transport across wide valleys and high hill-ranges the boulders of the till. Two hypotheses have been proposed in explanation of the manner in which the ice has acted. One of these was started by Agassiz. He assumed, as has been shown above, the former existence of vast sheets of ice, extending over the whole or the greater part of the British Islands, and contended that, by the constant seaward movement of this icy mantle, the surface of the country was ground down, polished, and covered with unstratified detritus. The second explanation is that most generally adopted in this country. It accounts for the rock striations by supposing that the country was in part, if not entirely, depressed beneath the sea; that icebergs drifting over the submerged land, and grating along its surface, produced the dressings already described, and that, as the bergs melted, the earth and stones with which they were laden fell to the bottom, and accumulated there to form what is now known as the boulder-clay.

This iceberg hypothesis, however, as was suggested in the introductory part of this memoir, must, I believe, be abandoned. It will not account for the phenomena. We cannot conceive of a set of ice-rafts moving for ages in one persistent direction within a given area of the sea. A group of huge bergs in high latitudes often exhibits, on the contrary, a scene of the wildest confusion. If we could examine some parts of the sea-bottom off the Greenland coast, we should find them bruised and scored in every direction by the grounding of the bewildered ice-floes.[1] But there would probably be many places which chanced to escape, and which showed, therefore, no trace of the passage of the ice.

The surface of Scotland, however, is found to be almost everywhere worn into rounded and flowing outlines, and the rocks, as we have seen, are often covered with striations. These markings do not occur vaguely and at random. They radiate from the main mountain masses, and continue down the long Highland glens, and away over the broad central valley of the Lowlands, with scarcely any deviation from their normal directions. Moreover, they mount steep slopes, and can be traced up and over hills from 500 to 800 feet high. Had these scores and striæ been produced by drifting ice, they would be found to run along the side of the hills; by no possibility could they steadily ascend them. In some instances, a deep narrow gully through a hill is seen to be completely smoothed and striated along its sides and bottom, and even the roof of an overhanging cliff exhibits the same markings, which conform to all the little dimples and clefts of the rock surface, and thus point to some agent which could press steadily and closely on the rock, descending into all its hollows, and mounting over its prominences. Now, it is needless to say, that these conditions are the very opposite of those required by the motion of an iceberg.

[1] See Sutherland, *Quart. Jour. Geol. Soc.* vol. ix. p 306.

Again, it has been supposed that the irregular, unstratified till affords some confirmation to the hypothesis of drift-ice. This deposit, it is asserted, is exactly such as might be inferred to be the result of the droppings of melting bergs and rafts of coast-ice. Some parts of the till may indeed have been formed in this way, but they are probably only exceptional parts. The till, as a whole, I am convinced, lends no support to the opinion, that it is an ordinary marine deposit. The first great objection to such a supposition, lies in the fact, that the till bears a close and constant relation, both of composition and colour, to the rocks on which it rests. Had this deposit been the result of the slow dissolution of sea-borne masses of mud-laden ice, it is manifest that such a relationship could not have existed but as an accident. The earth and stones thrown to the sea-bottom would then have varied according to the direction from which their transporting iceberg came. The spoils of different geological formations could not fail to be thus mingled together without any reference to the nature of the rock upon which they were discharged. But it is far otherwise with the Scottish boulder-clay. So intimately are its varieties of tint and composition connected with changes in the underlying rocks, as to form a reliable indication of the boundaries of the lithological groups that lie below.

Again, had the till been a marine deposit, it is scarcely conceivable that it should not have generally shown more or less distinct traces of stratification. It might not have been, perhaps, a well-bedded deposit, yet we should suppose, that there could hardly fail to be some lines marking at least where the fine impalpable mud settled down over the pebbles and boulders, which fell more rapidly to the bottom. Yet, such lines of deposition appear to be either extremely rare, or altogether absent in the till. The stratified layers which do occur, only serve to mark off more strongly the general unstratified character of the clay. Besides, they do not at all suggest the operation of the currents of the sea. Had the till been of marine origin, it seems also fair to suppose, that marine organisms would have been not unfrequently found in it, seeing that it is in many cases a stiff impervious clay, well fitted for the preservation of at least the more massive sea-shells and corals.

Such negative evidence is not, of course, of great value, more especially when we remember how wide an area is covered by those portions of the drift which are regarded as truly marine, and yet contain no fossils. In the latter case, however, the strata are chiefly of sand and gravel deposits, but ill adapted for the conservation of organic remains. Yet, in some parts of the Lowlands, this stratified drift has yielded sea-shells in profuse abundance: the true till, on the other hand, has scarcely yielded one;[1] its fossils have been terrestrial, not marine; the remains of land-plants and quadrupeds, not of fragile sea-shells.

After having myself held the iceberg hypothesis, I surrender it as wholly untenable. The agent which ground down, grooved, polished, and striated the whole surface of Scotland, has acted, not in the irregular spasmodic fashion of icebergs, floating along as impelled, now by the currents of the sea, now by the veering of the winds. It must have radiated from the central mountain-ranges, moving steadily downwards towards the sea, disregarding minor inequalities of the ground, and even mounting the steep slopes of considerable hills. It must have been a plastic agent that could adapt itself to the crevices of a cliff or of a ravine, pressing equally on hollow and prominence, everywhere rounding off and smoothing even the hardest rocks. It must have been an agent that could carry with it at once the finest particles of sand and large blocks of stone, and that could push these over the surface of the rocks in such a steady, leisurely way, that the large stone left a long straight rut like the track of a plough or harrow, and the grain of sand, a fine straight streak like the cut of a glazer's diamond.

The only agent in nature at present known to us which could consistently and simultaneously effect all these results, is land-ice, moving as modern glaciers do, from the higher parts of the country down towards the sea. By this explanation, originally proposed by Agassiz, and now in the course of being

[1] As already mentioned, Mr. Smith of Jordanhill states that he has found fragments of some of the stronger shells, such as *Cyprina Islandica*, in the boulder-clay, but such specimens are of extreme rarity, and, as I shall immediately show, are to be regarded as exceptional.

adopted by the geologists of Britain, the phenomena of the Drift become intelligible.[1]

The flowing outlines and planed surfaces of the crags and knolls over so large an extent of Scotland, are the exact counterparts of the *Roches moutonnées* of the Alps. The latter are known to be the results of ice-action; they have been produced by glaciers, which, grinding over them for an indefinite period, have left them in the form of long smoothed ridges, with curving hollows between. Such a contour could only be produced by the steady uniform abrasion of a heavy mass of ice moving slowly, and with a certain degree of plasticity over the ground. As the Scottish rounded rocks correspond in every essential respect with those of Switzerland, the inference of a like origin for both cannot be avoided.

Moreover, the *roches-moutonnées* of the Alpine tracts are covered with parallel striations, which indicate, in a not less impressive way, the nature of the agent that produced them, and the direction in which it moved. In like manner, the moulded rocks of Scotland are covered over with long parallel ruts and striæ, which cannot be distinguished from those in the regions of recent glaciers. The direction of these markings remains as steady and persistent in this country as it does in any of the Swiss valleys, and is as manifestly evidence of the passage of a body of solid ice across the surface of the land.

The fact that the striations and groovings are not confined to the Highland glens, where actual glaciers may well have existed, but extend far away over the Lowlands from sea to sea, seems sufficient proof that, although such markings are undoubtedly traces of the course of a moving body of land-ice, this ice could not have been in the form of a mere ordinary glacier. For the central valley is of greatly too large an extent ever to have been filled by any glacier which could descend

[1] For the views of British geologists who adopt the theory of land-ice, the reader should consult Professor Ramsay's interesting little volume on *The Old Glaciers of Wales*, and his papers in the *Quarterly Journal of the Geological Society;* also Mr. Jamieson's able papers, especially that in the number of the same publication for August last. Mr. Chambers differs from the other geologists in conceiving that the ice did not radiate from the mountains, but passed in one vast stream across the country from north to south. His papers are also quoted in the Appendix.

from the Highlands. Moreover, the same markings occur high on the sides and summits of the Highland mountains, which no glacier, in the usual sense of the term, could ever have reached. We have seen, indeed, that the striations occur almost everywhere, on high ground and low, from end to end of the island. If then it be true, as it plainly is, that these markings are in any one place evidence of the former existence of a stream of ice, their universality must also prove that the ice existed, not as mere local glaciers descending the chief valleys, but as one wide sheet covering the whole or nearly the whole of the country. Such a condition of things seems at first improbable, if not even impossible. Nevertheless, it has still its counterpart at the present day within both the Arctic and Antarctic circles.

Before attempting to point out how satisfactorily the details already given in this paper, are explained by the theory of a moving mass of land-ice, it may be of use to glance for a little at one of the regions which appear to offer the best illustration of the actual occurrence at the present day of phenomena similar to those whose memorials we have been tracing in the dressed rocks and boulder-clays of this country.

The present aspect of North Greenland probably affords us a close parallel to the state of Scotland during the earlier stages of the Drift period. The interior of that tract of country is covered with one wide sheet of ice, which, constantly augmented by fresh snowfalls, moves steadily downward from the axis of the continent to the eastern and western seas. This vast *mer de glace* frequently protrudes into the sea, where the line of cliffs subsides, and a valley opens upon the shore. The edges of such seaward extensions of the land-ice sometimes reach a distance of three miles from the land, until, when they are buoyed up on the salt water, and elevated by the rise of the tides, a hinge-like motion is produced, and large masses are detached to float away as icebergs.[1] But, even where no valley opens seaward, the ice may be seen exuding over the edges of the cliffs in huge hanging glaciers, from which great masses of ice tumble into the sea below. Looking inland from the peaks of some berg, or from the lofty coast-cliffs, the eye rests upon one wide sea

[1] See Sutherland, *Quart. Jour. Geol. Soc.* vol. ix. p. 305.

of snow, apparently following in its gentle undulations the in equalities of the ground which it buries. "The whole country," says Rink, "is covered with ice to a certain elevation, mountains and valleys are levelled to a uniform plane; the river beds are concealed, as well as every vestige of the original form of the country."[1] Here and there a dark mass of rock or precipice may be seen rising as an islet out of the surrounding ice. But the interior horizon is everywhere bounded by this frozen ocean. The Esquimaux are confined to but a narrow maritime strip. "If you point to the east, inland, where the herds of reindeer run over the barren hills unmolested, for they have no means of capturing them, they will cry 'Sermik,' 'glacier,' 'the great ice-wall;' there is no more beyond."[2]

The thickness which this ice-sheet sometimes shows where it protrudes upon the coast is enormous. Its average depth, says Dr. Sutherland, is 1200 or 1500 feet, of which one-eighth, or 150 feet, rises above water. In some of the valleys, however, the depth is considerably greater, since, at the foot of the glacier near Claushaven, the Esquimaux require lines of 300 fathoms to reach the sea-bottom.[3] Dr. Kane thus describes a vast glacier rising out of the sea, in a cliff, which extends for sixty miles between latitudes 79° and 80° N. "This line of cliff rose in a solid glassy wall 300 feet above the water-level, with an unknown unfathomable depth below it. It seemed, in fact, a great icy table-land abutting with a clean precipice against the sea. The interior, with which it communicated, and from which it issued, was an unsurveyed *mer de glace* or ice-ocean, to the eye, of boundless dimensions. A few black knobs rose from the white snow like islands from the sea. As the surface of the glacier receded to the south, its face seemed broken with piles of earth and rock-stained rubbish. Repose, however, was not the characteristic of this seemingly solid mass; every feature indicated activity, energy, movement. From one of the rugged islets, the nearest to the glacier which could be approached with anything like safety, I could see another island larger and closer in shore, already

[1] *Jour. Geog. Soc.* vol. xxiii. (1853), p. 148.
[2] Kane's *Second Expedition*, vol. ii. p. 210.
[3] *Quart. Jour. Geol. Soc.* vol. ix. p. 301.

half covered by the encroaching face of the glacier, and great masses of ice still detaching themselves, and splintering as they fell upon that portion which protruded. Long continuous lines of fracture, parallel with the face of the glacier, widened as they approached the sea, until they formed a gigantic stairway. It seemed as though the ice had lost its support below, and that the mass was let down from above in a series of steps. These split-off lines of ice were evidently in motion, pressed on by those behind, till at last they floated away in the form of icebergs. Long files of these detached masses could be traced slowly sailing off into the distance. A more impressive illustration of the forces of nature can hardly be conceived. Here was a plastic, moving semi-solid mass obliterating life, swallowing rocks and islands, and ploughing its way with irresistible march through the (frozen) crust of an investing sea."[1]

The great glacier of Melville Bay has been often described. It extends unbroken along the coast for forty or fifty miles, and loses itself inland in the vast ice-fields of the interior. When working his way across the Bay in 1857, M'Clintock observed two small islands almost enveloped in the glacier, and far within it an occasional mountain-peak protruding from beneath.[2]

But this icy mantle is not confined to the mainland; it is found to characterize some of the islands that fringe the coast. For instance, the island of Northumberland at the entrance into Smith's Strait, between latitude 77° and 78° N, has an interior sheet of ice, which, being of course completely isolated and washed by the sea, is necessarily dependent for its increase upon the snowfall of a very limited surface. "Yet it sustains in its discharge no less than seven glaciers, perhaps more, one of which is half a mile in diameter, by two hundred feet in

[1] Kane's *Second Expedition*, vol. i. pp. 225-228; ii. pp. 146-153. I have taken the liberty of selecting from different passages descriptive of this glacier, such sentences as seemed best adapted to elucidate the conditions which are suggested by the Scottish boulder clay.

[2] *Narrative of the Discovery of the Fate of Franklin*. He remarks further:—"From observing closely the variations in the glacier surface, I think we may safely infer, that where it lies unbroken and smooth, the supporting land is level; and when much crevassed the land beneath is uneven." "Some attempts to cross the glacier in South Greenland have failed."

depth." The cliffs of this island are lofty, and from their summits the ice may be seen creeping down in great masses. "It seemed," says Kane, "as if a caldron of ice inside the coast-ridge was boiling over, and throwing its crust in huge fragments from the overhanging lip into the sea eleven hundred feet below."[1]

Even in such a climate, however, the genial influences of summer are not unfelt. From under the snow in the maritime valleys, saxifrages, carices, ranunculi, willows, mosses, and heaths push out their young shoots among the withered leaves of the previous year.[2] They rapidly acquire maturity, and when the short Arctic summer is over, are again enveloped in snow. The rise of temperature which gives life to the sleeping vegetation, loosens also the rivers and runnels. Down the face of the great Humboldt glacier, cascades and water-tunnels tumble merrily in the sun. The belt of sea-ice which fringes the land is cut through by numerous torrents, and sometimes even by large streams. The Minturn river is described as about three quarters of a mile wide at its mouth, and admitting the tides for about three miles. It is a roaring and tumultuous body of water, rolling with the violence of a snow-torrent over a bed of broken rocks. From the base of a glacier it issues in numerous streams, which unite into a single trunk about forty miles from the sea. In the valley traversed by this river, the scanty but richly-tinted Arctic flora blooms among the rocks. In such sheltered places, too, may be seen the musk-ox and the reindeer, and often the mouldering cabins of the Esquimaux.

The intensity of the winters is seen not less markedly on the sea than on the land. The surface of the ocean freezes over into a solid crust, sometimes smooth as a white plain, sometimes broken up into masses of frozen ruin, according to the absence or

[1] *Op. cit.* vol. i. 463; ii. 259. Speaking of the tracts about latitude 71° and southwards, Rink remarks that the height of the great ice-field is about 2000 feet, below which the snow annually melts, and that it is from this elevation that the perennial glaciers drain down into the long narrow fiords.—*Jour. Geog. Soc.* vol. xxiii. p. 151.

[2] No fewer than 264 species of flowering plants are enumerated from Greenland. These are of course most abundant in the more southerly tracts of the country, but even north of lat. 73°, seventy-six species, belonging to forty-four genera, and these to twenty families, are known to exist.—See Kane, *Lib. cit.* vol. ii. p. 447.

prevalence of storms during or subsequent to the process of solidification. This solid crust rises and falls imperceptibly with the tides. But along the margin of the land the tidal changes produce some important geological results. When the sea begins to congeal, the first crust rises with the next tide, and is borne up upon the land, where it freezes, and where, on the retreat of the tide, it is left as a table or shelf of ice fringing the coast-line. This shelf conforms to all the sinuosities of the coast-line, and is known to the Danes as the "eis-fod," or ice-foot. It annually disappears as high as Upernavic or even Cape Alexander, but northwards it remains all the year round. It attains a thickness of from 25 to 30 feet, but where it is pushed up by the grinding of the floes it is sometimes as much as 60 or 70 feet. In breadth it reaches 120 or 130 feet, sometimes in two or three terraces that rise from the frozen surface of the sea.

This ice-belt is one of the most interesting geological agents of the Arctic regions. When the water begins to freeze, it encloses the pebbles and boulders that lie along the beach. These, as the ice rises on the shoulders of the tide, are carried up with it, and others are encased in the next layer that freezes. In this way the bottom of the ice-foot becomes charged with rocky detritus. Moreover, when the thaws of summer have fairly set in, large masses of crag are detached from the cliffs overhead, and find a resting-place on this shelf of ice.[1] Instead, therefore, of a level platform of pure glistening ice, rising twenty or thirty feet above the surface of the frozen floes, the ice-foot becomes, in many places, an impassable chaos of fragments of ice and rock. The streams and thaws of summer, together with the tides, unite in disengaging great masses of it from the coast-line; large bergs and floes, too, are sometimes driven against it, and carry away the growths of many years. Along the shores of Marshall Bay, Dr. Kane saw the surface of the ice-foot covered with millions of tons of rubbish, and he was able to trace away out

[1] "The rocks above us, just released from the frost which had bound them so long and closely, were rolling down the slopes of the debris with the din of a battle-field, and absolutely clogging the ice-belt at the foot. Here and there, too, a large sheet of rocks and earth would leave its bed at once, and gathering mass as it travelled, move downward like a cataract of ruins. The dogs were terrified by the clamour, and could hardly be driven on till it intermitted."—Kane, vol. ii. p. 225.

upon the frozen waters of the bay, raft after raft of the ice-belt of the previous year, that had been caught by the winter on their way south, laden each with a heavy freight of foreign material. He also remarks that he found many miles out to sea, symmetrical tables detached from the ice-belt 200 feet long by 80 broad, seemingly impregnated throughout with detrital matter, and covered with large angular blocks and boulders, which were sometimes polished and striated.

The important geological bearing of the operations of this ice-belt will better be seen, however, when we pass to the consideration of the marine parts of the Drift.

If now we apply the existing conditions of the Arctic regions to the elucidation of the phenomena of the striated rocks of Scotland, the subject becomes at once intelligible. The former extension of a vast icy mantle over the surface of our island accounts well for the character of the *roches moutonnées,* and for the divergence of the striations from the main ridges of the country. We see at the same time how these markings should not be confined to the valleys, but run along and over the sides and summits of the hills. We see how masses of ice, many hundred feet in thickness, must have accumulated in the Highland glens, overflowing into the adjacent valleys, and seeking egress towards the sea by crossing over ranges of high ground, as in Gareloch, Bute, and Cantyre, where, it will be remembered, the striations on the rocks run up and over the ridges, and are as clearly shown on the hill-tops as in the valleys. From the great chain of heights extending from Argyleshire to the north-east of Aberdeenshire, there would be a constant drainage of ice towards the south-east into the low grounds of Forfar, Perth, Stirling, and Dumbarton. The stream would abut against and overflow the chain of the Kilpatrick, Campsie, and Ochil hills, forcing its way at the same time through all the transverse valleys of these heights, so as to debouche upon the long central undulating plain of the Clyde and Forth. From the high grounds of Lanarkshire and Peebles, extending north-eastward by the Moorfoots and Lammermoors to the North Sea, the ice would, in like manner, descend upon the plain, and join the Highland stream. The united mass would thus cover the wide area of the central Lowlands. The eastern part would move eastward, down the valley of the Forth, and this direction corresponds, it will be remembered, with the trend of the striations in that district. The western portion from about Tinto, westward, probably moved towards the Atlantic, but for this the evidence has not yet been collected The Firth of Clyde and its tributary fiords must have been filled well-nigh to the brim with ice, which travelled on the whole, southwards, varying to the east or west of south according to the form of the ground. This is shown by the striations in Knapdale, Bute, Gareloch, Holy Loch, the Cumbraes, and by the remarkable terrace-like moulding of the hill-sides bordering the sea, as between Dunoon and Inellan. Perhaps the drainage from the northern slopes of the Ayrshire hills may also have streamed into the Firth of Clyde, so as to join the mass that descended from the Highlands. From the northern side of the Grampian chain the ice must have moved down upon the Moray Firth, being there joined by the drainage of the northern and eastern slopes of the mountains of Inverness, and the united mass would be still further increased by the stream from the eastern declivities of Ross and Sutherland. Down the whole of the west coast, from Cape Wrath to the Mull of Cantyre, one long expanse of ice filled up the fiords, and stretched out into the Atlantic. From the uplands of Wigton and Galloway, the icy stream swept down into the valley of the Solway, and onward for Ireland. From the hills that border the lonely valley of Liddesdale, far away into the blue Cheviots, the same universal mantle of ice threw its folds athwart the hills and dales of the north of England.

The thickness of this ice-sheet must have been very great in some places. It would, of course, reach its chief development in the valleys. There it must often have exceeded 2000 feet in thickness. Mr. Maclaren mentions in a paper already quoted that he has traced the general striation of the surface to the height of more than 2000 feet. The same markings may be followed from the summit of the ridge between Loch Awe and Loch Fyne, at a height of 1800 feet, down to beneath the level of Loch Fyne. This fiord is about 624 feet deep in its deepest part, and is probably striated along the bottom from end to end. Hence it would appear that a stream of ice filled up this deep and wide valley, and rising to a height of 2400 feet or more above its bed, so as to overtop the adjacent heights, moved steadily downwards from the north-east. Mr. Jamieson has given another striking example of the depth and volume of the ice in one of the glens round Ben Nevis. Glen Spean he shows to have been filled with a stream of ice at least 1300 feet in depth, and two miles broad at the surface.[1]

Constantly augmented by fresh falls of snow, this wide covering of ice would steadily descend from the main water-sheds of the country, spread out over the lower grounds, and extend for a greater or less distance to sea, until, broken up by the waves, by changes of temperature, or by other causes, it was dispersed over the ocean in the form of wandering icebergs. The whole country was thus probably sealed in ice, save, perhaps, some high cliffs and craggy precipices. There is reason to think that the general height of the land above the sea was greater at that time than at present. But the present main hill-ranges and valleys probably existed, and served to guide the moving ice in its downward progress to the ocean. Steadily descending, century after century, from mountain-top to sea-shore, this massive wintry sheet ground down the face of the country to an extent almost inconceivable. As its ceaseless abrasion went on, hills must have been sensibly lessened, glens widened and deepened, lake-basins hollowed out, and new valleys excavated. To this process many of the more characteristic minor features of a Scottish landscape must be attributed. The rounded and flowing outlines of the hills, the smoothed contour of the knolls, and the long banks of boulder-clay, all tell of the passage of the great ice-flow.

But there are some features of the abrasion which require a more detailed notice here. In describing the general moulding and striation of the country, I referred to certain other proofs of extensive abrasion, which would be more advantageously considered in the discussion of the nature of the agency from whose operations they took their rise.[2] Though the rounded and moulded aspect of the island suggests at once an extensive denudation; and though our ideas of the magnitude of this waste

[1] *Quart. Jour. Geol. Soc.* xviii. 174.

[2] See *ante*, p. 25.

are vastly augmented when it is ascertained that the boulder-clay is nothing but a mass of ruin, derived from the surrounding hills and valleys, yet it may be doubted whether we do not obtain a still more impressive conception of the enormous extent to which the country was ground down during the Drift period, when we consider the structure of many of our valleys and lake-basins, and discover that these deep depressions have been either wholly or to a large extent scooped out by the same agent which striated the island and produced the till, viz., a vast moving body of ice.

To my early friend and colleague, Professor A. C. Ramsay, belongs the merit of having propounded what will assuredly be at last accepted as the true theory of the origin of those rock-basins of the Alps, and of the northern hemisphere generally, which are occupied by lakes. To his masterly paper on this subject, published in a late number of the *Quarterly Journal of the Geological Society*, I must refer for the full details and argument.[1] He shows, as it appears to me unanswerably, that the innumerable rock-basins (that is, cup-shaped hollows of greater or less depth scooped out of rock) found all over those countries which can be shown by other evidence to have been extensively glaciated during the Drift period, can only be accounted for by the operation of ice. To take, as examples, innumerable lakes scattered over both the Lowlands and Highlands of Scotland, it can be shown that they are not dammed up by loose materials, that they do not lie in mere hollows produced by foldings of the earth's crust, nor in lines of open fissures, nor in areas that have been locally depressed. Neither can such basins have been produced by mere running water. A river may out of solid rock scoop a deep valley, but not a lake-basin. In short, the only agency known to us by which such basins could be excavated, is that of moving ice.

Where the ice flowed along lines of valley, it would receive a downward vertical grinding motion wherever it met with such an obstruction as a narrowing of the valley. The moving mass would thereby be increased in height, and the augmented vertical pressure, combined with the arrested onward progress, would give rise to a powerful erosion of the bottom of the valley at

[1] *Quart. Jour. Geol. Soc.* vol. xxiii. p. 185.

that place. If the process went on for a sufficient length of time, it is evident that a deep basin cut out of the solid rock would be the result, and on the retirement of the glacier this basin would become a lake. A similar excavation might take place even where the ice met with no strangulation in its course down the glens. If, at any point, the nature of the rock was such as to yield to the erosion more rapidly than the surrounding parts, a hollow would be formed, and once formed, it would go on increasing in depth every year. In the same way, on wide open tracts, away from hills, the ice might well scoop out similar troughs, taking advantage as it would do of any inequality in the surface or texture of the rocks. Hence, such rock-basins could have been produced even on the tops of hills. Of this, several instances were examined by Professor Ramsay and myself, among the Cleish Hills of Fife. From some of the hill-tops in Ross and Sutherland, the wild rugged surface around is seen to be dotted over with tarns and lakes; indeed, they seem there to be scattered broadcast over the country.

With this view of their origin, I know hardly any phase of the geology of Scotland more calculated vividly to impress the imagination, than the contemplation of the Highland lakes and glens, and the deep fiords of the western coast. To the eye of the ordinary observer, these scenes seem monuments of primeval chaos and convulsion. He sees in these

> Crags, knolls, and mounds, confusedly hurled,
> The fragments of an earlier world,

and in these deep glens and lochs, traces of yawning rents and chasms which were burst asunder when the earth was young. Such pictures are indeed not without their attractions. Yet, I know not that these wild scenes do not rise at once in dignity and grandeur when we regard them, not as the chance effects of some sudden and random cataclysm, but as the accumulated results of all the destructive influences of nature working together steadily and mightily through the lapse of untold ages; movements of upheaval and depression of the earth's crust, waves of the sea, rain, springs, frosts, rivers, and, not the least powerful of all, the massive, resistless glacier.

There are also some remarkable gullies and clefts along the hillsides both of the Highland and Lowland tracts of Scotland.

These I have partly alluded to as evidence of the presence of the same great abrading agent which has rounded off the general surface of the country. I intended to have given a fuller description of them here, but I shall reserve them to another occasion, more especially as they are at present under investigation by the Geological Survey in the Silurian uplands of the south of Scotland.

The mystery that has so long hung over the boulder-clay, if not wholly, is at least in great part removed, when the existence of a great sheet of land-ice is once admitted. On the old iceberg hypothesis we might perhaps conceive of a rudely arranged accumulation of clay, earth, and boulders, underneath the sea. But we could never by such an agency explain the local character of the boulder-clay. If that deposit had been formed from the chance melting of earth-laden bergs, why should it present so constant and so close a relation to the nature of the rocks on which it rests? Ought it not unquestionably to have no reference to the nature of its floor, having derived its materials, if this explanation were true, from above and not from below?

But when we admit the boulder-clay to be evidence of the abrasion wrought by a vast sheet of land-ice in its passage to the sea, these and many other difficulties disappear. We see that such a clay must necessarily take its colour and composition from those of the rocks underneath, out of which it has been produced. As the ice moved on, the fragments detached from the rocks over which it passed, must of necessity have been worn down more and more the further they were carried onwards with the ice, until they were reduced at last to mere pebbles, or pounded down into the finest sand and mud. As these stones were in the process of reduction, fresh fragments constantly augmented the mass that was being crushed and ground together by the ceaseless march of the ice. And thus, the greater number of the stones would almost always consist of fragments from the rocks of the district, changing character as the ice passed from one geological formation to another.

Another feature in the boulder clay which becomes now at once intelligible, is the constant striation of the boulders. Steadily crushed together amid sand and mud, and ground over the hard rock below, they could not fail to be everywhere striated and grooved, and also to leave their ruts and scratches on the surface of the rock over which they were pressed. While moving onward, they would have a natural tendency to arrange themselves in the position in which they would undergo the least friction, that is end on. And so we find them very commonly striated in the line of their longer axis.

We can understand too, why, when a direction of transport is indicated by the materials of the boulder-clay, it should be found to coincide with the trend of the striation on the rocks of the district, since they both have resulted from the movement of one common agent. The tumultuous pell-mell agglomeration of these materials is likewise at once explained. By such a process of transport they could not have undergone any arrangement. In these respects, the boulder-clay is fairly comparable with the terminal moraine of a glacier.[1] In either case, there is an unstratified accumulation of sand, clay, earth, and boulders, carried along by ice, and left where the ice melted. Yet there are some strong differences between them, which serve still further to show, that the old glaciation of the country could not be the work of any mere ordinary glaciers. In the lateral or terminal moraine of a recent glacier, the angular and subangular stones form a large proportion of the whole; the number of scratched stones is exceedingly small. In the boulder-clay, on the other hand, the rounded and subangular forms are largely in excess, and the percentage of striated stones is great. The reason of this difference seems to be, that the moraine of a glacier is to a large extent composed of debris, which has fallen upon the surface of the ice, and has thus been carried down without undergoing any trituration, except what may be caused by the rolling of the stones over each other as the ice below and around them slowly melts away. These stones are then shot over the end of the glacier, where they join

[1] The kind of glacier detritus, however, which offers the closest analogy to the boulder-clay, is the bed of mud and stones on which the glacier rests, and which it is constantly pressing onwards. This was distinguished by Martins (*Revue des Deux Mondes*, 1847) as a distinct form of *moraine*. Hogard in his work on the Drift of the Vosges, describes it as "la moraine profonde, comprenant la couche de sable et de cailloux ou galets qui supporte le glacier et le sépare du roc sous-jacent, et se nivelle sous l'action de ce puissant rouleau compresseur" (p. 10).

those that have been ground down in a passage below the ice. But, in the case of the boulder-clay, it is probable that the whole, or nearly the whole of the stones were transported below the ice, since there could have been little or no exposure of bare rock when the great mantle of ice spread itself over the country. Hence, in the one case, we find a confused heap of angular stones, which have been carried along *on* the surface of the ice; in the other an equally bewildering assemblage of rounded and striated stones, which have been pushed and ground along *under* the ice. Agassiz long ago saw the meaning of this difference, when British geologists had hardly begun to realize the existence of a great European glacial epoch. "In Britain," he says, "the ice, at the time of its greatest extension, seems to have covered completely great tracts of country, and consequently rendered the fall of blocks on its surface, if not impossible, at least extremely rare, so that the great mass of the blocks was necessarily buried under the ice, and was therefore subjected to all the effects of a gradual and long-continued trituration, just as is observed beneath the glaciers of the present day."[1]

By admitting the former presence of a vast moving sheet of ice, we obtain in like manner a satisfactory explanation of the

[1] *Edin. New Phil. Jour.* vol. xxxiii. 232. Mr. Robert Chambers, who has so ably maintained the doctrine of a great sheet of ice as necessary for the explanation of the phenomena of the earlier part of the Drift period, infers, that this ice could not have been everywhere in the same condition as the ice of a recent glacier, "for there is a difference in the character of its detritus." "The boulder-clay," he says, "indicates a comparatively fluid state of the ice."—*Ibid.* vol. liv. 279. For this supposition, however, it does not appear to me that there is any necessity. The drainage from springs would of course rise up under the ice, and make its way as it best could to lower levels. But the ice itself was doubtless as good solid ice as that of any Greenland glacier of the present day. The real cause of the difference between the detritus of a modern Alpine glacier and the boulder-clay is, I imagine, that which is given in the text. It is interesting to compare the deductions of Hogard from the erratic phenomena of the Vosges. He, too, infers that the great sheets of detritus on high grounds in that district were produced when the whole region was under ice. "Dans la partie des Vosges," he says, "où ces nappes se rencontrent hors des vallées, on ne voit aucune trace de moraines latérales ou frontales; et les dépôts inférieurs se trouvant seuls, il y a lieu de présumer qu'au moment où ils se formaient, *le massif des montaignes était entièrement recouvert de nevés et de glace, et que nulle cime ne dominant les glaciers, ceux-ci étaient alors entièrement dépourvus de débris à leurs surfaces supérieures.*" — *Coup d'œil sur le terrain erratique des Vosges*, 1851, p. 66.

broken and crumpled appearance which the rocks often exhibit under the boulder-clay,[1] and also of the occasional interjection of the clay between the joints and bedding-planes of the underlying rocks.[2] These phenomena point to the slow passage of an immensely weighty body across the country, whereby the strata were sometimes broken or bent back upon each other, or were pushed along or lifted up in mass, and set down on a mass of clay and stones, perhaps at some distance from their original position.

When the details of the stratified beds in the boulder-clay above described are attentively considered, some interesting insight is, I think, obtained into the history of the deposit. The little nests of sand, often contorted, and always of very limited extent, point probably to the action of little runnels, either flowing over the clay when the ice had for a season retreated, or rather, perhaps, working their way onward beneath the ice, as glacier streams do at the present day. The contortion of the bedding might arise either from the deposition of the sand over pieces of ice which afterwards melted, or from the weight and onward pressure of the mass of moving ice overhead. In the case of an Alpine glacier, the water which rises to the surface of the earth in springs, or which percolates through crevasses and joints in the ice, flows on underneath the glacier, and issues from its extremity a full-formed river charged with the mud which has been produced by the trituration of the stones and rocks over which the ice has ground its way. During the formation of the boulder-clay, when the cold was at its severest, such water drainage as existed must have gone on under the ice in the same way, save that when the whole country was ice-covered, the water would find its way to sea without reaching the open air at all.[3]

[1] See *ante*, p. 33. [2] See *ante*, p. 47.

[3] "Springs, properly speaking, as outlets of subterranean drainage, are almost unknown in North Greenland. At Godhavn, Disco, there is a permanent spring with a winter temperature of 33·5° Fahr., but the so-called springs of the Danish settlements as far north as 73°, are derived from a surface drainage, which is suspended during the colder months of the year."—Kane, *Second Expedition*, vol. i. p. 453. The same observer states, however, on the authority of the natives, that a stream issuing from the foot of a glacier into a lake at Etah in latitude 78° 3′, continues to flow on, even under the thick ice which covers the lake during the winter. *Op. cit.* vol. ii. p. 208.

But though from the universal moulding and striation of the rocks it seems undeniable that the whole of the country must have been glaciated, it is scarcely likely that one vast and unbroken sheet of ice and snow would continue, year after year, completely to conceal the land. Even in North Greenland we know that this is not the case, for there every summer sees tracts of ground arrayed in verdure and wild flowers.

In like manner, there is, I think, good evidence to show that even during the accumulation of the Scottish till, this extreme rigour was not the constant and universal condition of the climate. The stratified beds in the till indicate, apparently beyond a doubt, the existence of streams and lakes during that period. They show, further, that these waters were open to the day, and that, though the drainage of the country may perhaps have sometimes progressed under the ice, yet that there were seasons when some of the valleys were at least so far free of frost and snow, as to allow streams and runnels to work their way along the freshly exposed surface of the lately-formed boulder-clay. Moreover, in the deposits left by such streams, we find branches of trees and layers of peat. Even if it were contended that the peat did not result from the growth of vegetation on the spot, but was merely drifted vegetable matter which might have been carried along under the ice, still it must be allowed, that there could not but be some parts of the country where the soil, open to the air and light, supported a growth of plants. And the existence of branches in these drift-beds is a sufficient indication that such patches of soil must have remained free of ice, not for one summer only, but for a succession of years, so as to admit of the growth of mere seeds into hardwood shrubs or trees. The peat, however, doubtless grew on the spots where we now see its remains, that is, along the water-courses and pools of the valleys. Although, therefore, all the higher grounds, and perhaps some of the main valleys in the lower tracts of the country down to the sea-level, may have remained sealed up in the snow and ice throughout the period represented by the boulder-clay, it is nevertheless certain, that there were intervals when certain valleys, up to a height of at least 800 or 900 feet above the present sea-level, were so far free from the frozen envelope, that streams of water gushed along their bottoms, and vegetation bloomed adown their slopes. It was doubtless in such fertile hollows that the hairy elephant and the reindeer found their food.

Glimpses of these ancient conditions seem to be afforded by the nature of the localities in which the mammalian remains of the Drift occur. They appear, in almost every case, to have been found in valleys not far from the banks of some stream. Those of Kilmaurs lay close to the Carmel Water; the tusks of the Union Canal were taken out of the cliffs of till that overhang the Almond; those of Chapelhall occurred in the upper part of the till which fills up the same old basin already described; the reindeer antler of Dumbartonshire was found not far from the course of the Endrick. The frequency of this association of the bones in valleys can hardly be accidental. I believe it will be found to receive its explanation in the probable existence of these valleys during the boulder-clay period, when they were traversed, during at least the summer months, by streams issuing from the adjacent ice-fields, and were thinly covered over with a scanty Arctic flora. In such valleys the herbivorous mammals would naturally congregate, and the remains of these animals would be much more likely to be preserved there than if they were left on the snowy surface of the surrounding uplands. Dr. Kane mentions the occurrence of the skeleton of a musk-ox in a frozen pasty silt along the eastern shores of Smith's Straits. "The table-lands and ravines about this coast," he says, "abound in such remains. Their numbers, and the manner in which they are scattered, imply that the animals made their migrations in droves, as is the case with the reindeer now. Within the area of a few acres, we found seven skeletons and numerous skulls; these all occupied the snow-streams or gullies that led to a gorge opening on the ice-belt [along shore], and might thus be gathered in time to one spot by the simple action of the water-shed."[1] Dr. Scouler's four elephants and a half, found within the area of a few yards, in the valley of the Carmel Water, could hardly have been carried to that spot by icebergs or currents of water. It is much more likely that they formed part of a herd or herds which browsed on the banks of the ancient Carmel, and that dying

[1] *Second Grinnell Expedition*, vol. i. p. 95.

there, their bones were buried under the mass of earth and stones pushed forward by the next advance of the glaciers that filled the higher part of the valley.[1]

The occurrence of the stratified deposits in the Scottish till further indicates that although the intervals of quiet and vegetation may have lasted for many years, they were in the end brought to a close by the return of severer winters, when the ice once more crept down the valleys which it had abandoned, and began anew its ancient powers of abrasion and waste. The water-courses in the till at Chapelhall and elsewhere are covered over with coarse boulder-clay like that below, showing that the old conditions again assumed their sway. The striated pavements in the boulder-clay may also, perhaps, indicate the renewed advance of the ice-sheet, grinding its way over its ancient and partially consolidated floor of detritus, just as it had done over masses of solid rock; or, as I have already suggested, they may point to the later period of submergence when ice-rafts grated over the depressed surface of the land.

But if this vast moving mass of ice, after having for a while retreated to the higher grounds, once more found its way into the valleys, why did it not clear out the deposits left there by the streamlets and lakes? I would answer that it almost always did so. If it had not swept them away, they would probably be found in abundance. Those which exist ought to be regarded rather as exceptions, which have been preserved by a fortunate concurrence of circumstances. It is not difficult to understand how a narrow water-course should be preserved by being choked up on the advance of the ice, which might then pass over without entirely effacing it, more especially as the water-drainage under the glacier would tend to renew it at the first opportunity. Such broad deposits as those of the Chapelhall basin present a greater, yet not, I think, an insuperable difficulty. At the outset it must be borne in mind that these

[1] This may have happened close to the sea-shore, as in the case of Dr. Kane's musk-ox, and sea shells might either be thrown up by high tides over the bones previous to their entombment, or be deposited above them during the slow sinking of the land. I mention this as a possibility, in order to show, that should the shells alleged to have been found with the elephant remains at Kilmaurs, prove to be actually marine, no difficulty need be felt in harmonizing such a fact with the hypothesis that the boulder-clay is a deposit from land-ice and not from icebergs.

deposits are sometimes overlaid by the till with the most perfect regularity, and that in other places, as already shown, they exhibit traces of having been subjected to a good deal of pressure. It does not appear impossible that the ice, slowly advancing and pushing before it a vast pile of detritus, might so fill up a basin like that of Chapelhall as not greatly to disturb the fine sands and clays deposited at the bottom, but to pass on grinding down the mass of debris which it had previously pushed over them. And unless the onward march of the ice was continued so long as fairly to wear down the overlying rubbish, and reach the stratified deposits of the basin, the latter might perhaps escape.

But we must remember that the increased severity of climate indicated by the renewed advance of the ice-sheet must have told on all the waters of the country. Streams, rivers, and lakes would be frozen over, and, where of no great depth, the lakes might be frozen to the bottom, and thus form solid sheets of ice.[1]

If then we conceive that the basin in which the Chapelhall sands and clays were deposited was thickly frozen over, it does not seem difficult to understand how the advance of the ice-sheet might push such a quantity of the old boulder-clay into the basin as even to fill it to the brim, without so much as loosening a pebble from the beds of sand and clay that lay secure below the frozen lake. The ice might then override the whole, and after wearing down perhaps a large part of the stiff clay and rubbish which it had emptied into the basin, it might finally retire without ever having found its way down to the bottom of the lake. In course of time the ice of the lake would melt, and in so doing, it would let the overlying till fall down on the lacustrine beds. The junction might in many places be effected gently, the one deposit being lowered by imperceptible degrees upon the other. But this would not always be the case. Owing to unequal melting of the ice, or to vertical pressure, or to both combined, some portions of the till would be forced upon the beds below, squeezing and contorting them,

[1] Dr. Sutherland, in his account of Captain Penny's voyage to Wellington Channel in search of the Franklin Expedition, mentions a number of lakes near the beach, which were frozen to the bottom, though the depth of some of them was more than two feet.

and even penetrating among them like dykes and veins of an igneous rock. Such, it will be remembered, are exactly the appearances now visible along the junction of these stratified beds with the overlying till in the pits of Chapelhall.

If these inferences are just, we have advanced some way in an elucidation of the history of the early part of the Drift period in Scotland. It appears that the island was covered, as large tracts of Greenland are, with a wide sheet of snow and ice, which, constantly augmented by fresh snowfalls, pushed its way outward from the main mountain chains towards the sea; that there were periods of varying climate; that sometimes many of the valleys glowed with the vegetation of an Arctic summer, rills of water trickled down their sides or dashed over their rocky ledges, and herds of huge mammals pastured in their solitudes; that again the cold increased, and the ice, once more pushing down the valleys, buried their beauty under one wide pall of cheerless desolation.

Some reasons may now be given which render it probable that, while these changes were going on, the country was sinking beneath the sea. Even those who hold the till to be a marine deposit admit the necessity of such a submergence.

At the outset, it must be confessed, that we have as yet no data for computing what may have been the general level of the island, either at the beginning of the glacial period, or at the time of the greatest extension of the ice, or whether the early part of the period did not witness an actual rise of the land. From several considerations it has been deemed probable, that during some part of the glacial period, most likely at the time when the cold was severest, this country stood considerably higher above the sea than it does now. The whole of the present surface of the land, even away out under low-water mark, has been dressed and moulded by the ice-sheet. If, therefore, the land was no higher at that time than it is now, the ice must have everywhere gone out to sea in one vast glacier. Though it cannot be affirmed that such a condition of things is impossible, it is difficult to conceive of its existence between latitudes so low as the 54th and 59th parallels. Even in Greenland at present, the ice does not everywhere reach the sea. Moreover, if the land was no higher than at present, it can be shown that the ice must have descended into the sea, sometimes to a depth of more than 600 feet, and travelled there for many miles. Loch Fyne, for instance, has been already pointed out as a conspicuous example of this old glacial erosion. From the head of the loch to the hills between Loch Gilp and Tarbert is a distance of thirty miles. The depth of the loch, as shown by the Admiralty soundings, is sometimes as much as 624 feet. Now the ice must have travelled the whole length of this deep valley (indeed, it probably to a large extent scooped it out), until, when it reached the bend of the loch at Knapdale, it went right over the Knapdale hills into the Sound of Jura.[1] But the islets between Islay and Jura and the mainland, show the characteristic moulding; the ice would therefore seem to have held on its way across the Sound, and joined the masses that descended from the Jura and Islay mountains. The waters of the ocean for many square leagues would in this manner be excluded from their ancient domain. But this is only one instance. The same facts are presented more or less completely by all the fiords of the western coast. Even the valley now occupied by the Firth of Clyde must have been filled with ice, as is well shown by the striations in Bute and the Little Cumbrae.

Along the Greenland coast sheets of ice a thousand feet in thickness are pushed out for several miles seaward. It is not impossible, therefore, that the ice of our Scottish fiords actually usurped the place of the sea. But it seems more credible to suppose, that what are now sea-lochs were then land valleys filled to the brim with rivers of ice, in other words, that the land was considerably higher than at present. The increased elevation would enlarge the snow-fields, and thus augment the mass of ice that was ever grinding its way over the country onward and downward to the sea.

But whatever may have been the extreme height of the land during the epoch represented by the boulder-clay, I think it can be shown with no small degree of probability, that while that deposit was in the course of formation, the country was slowly sinking. In the first place, the series of drift-beds which immediately succeeds the boulder-clay is of marine origin, and

[1] See *ante*, p. 21, and Mr. Jamieson's Paper there cited.

has been traced up to a height of many hundred feet above the present sea-level. Either therefore the land must have been sinking during the boulder-clay period, or in the interval between the formation of that deposit and the deposition of the highest of these marine beds. That the depression went on while the boulder-clay was forming, seems to me probable—

1*st*, From the occurrence of marine shells in the boulder-clay at a higher level than beds of peat in the same deposit. The Chapelhall drift-beds, already so fully described, make this point sufficiently clear. The shells which occurred in a bed of brick-clay lay perhaps 200 or 250 feet above the strata of clay and sand with peat and branches of wood. All these deposits were in the true till. The conclusion therefore is, I think, irresistible, that there must have been here a sinking of the land to the extent of more than two hundred feet between the deposition of the peat-beds and that of the clay containing marine shells. This depression went on at the same time that the till of the district was forming, for the evidence of its occurrence is preserved in that till. We thus see that what was the bed of a lake or river at one part of the boulder-clay period, became at a later date in the same period the bed of the sea. And this is probably only an earnest of the kind of evidence which still lies stored up in the boulder-clay to reward the researches of the future.

2*d*, The continuity of the boulder-clay over so large an extent of surface seems adverse to the supposition that this deposit underwent so long a process of denudation as would be involved if it was first exposed to the waves during a slow submergence below the sea-level, and then wasted afresh during a process of re-elevation. That it did undergo not a little degradation from the action of the sea is indubitable, but if it had been twice exposed to the waves, I cannot but think that the degradation would have been greater.

3*d*, As a corollary to the preceding inference, it may be suggested, that the comparative scantiness of the marine drift (which will be considered in detail in the succeeding section of this paper), appears to militate against the idea that it is the combined results of wave and current action during first a submergence and then a re-elevation of the land, when wide tracts of soft clay and earth were exposed to the full sweep of the sea. The meagreness of this drift is indeed sufficiently puzzling even on the supposition that the beds of marine clay and sand were formed out of the till, when the land, after having been depressed, was again ascending. But it seems wholly inexplicable on the other hypothesis, which would make the marine drift the memorial at once of the depression and upheaval of the land.

If it be admitted that while the boulder-clay was in the course of being slowly ground up by the vast mass of seaward-moving ice, the whole country was undergoing a movement of subsidence, most, if not all, of these difficulties are removed. The ice pushing its way out to sea would be broken up and dispersed as icebergs; but a fresh stream would continue to pour down from the interior. The slow sinking of the land would greatly modify the outline of the coasts, and would, of course, constantly decrease the area of the ice-fields. But the boulder-clay, protected by the sea-ward extension of the great glacier, would, as a rule, be carried down beneath the sea without ever coming in contact with the waves. Large portions of the upper part of the deposit might thus be actually formed by land-ice, yet below the level of the sea. Other parts might arise from the droppings of bergs detached from the main sheet of ice. The till of Caithness was probably formed in one or both of these ways. Its shells are nearly all rubbed, many striated and broken.

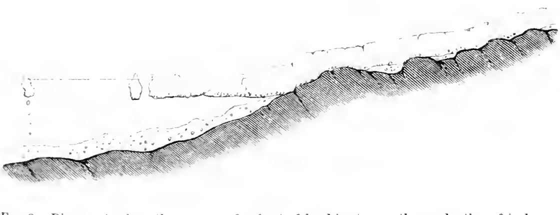

FIG. 3.—Diagram to show the passage of a sheet of land-ice to sea, the production of icebergs, and the accumulation of detritus both on the land and on the sea-bottom.

We thus see how organisms both of the land and the sea may be found in the till, and yet their occurrence there be satisfactorily solved. The beds of peat and river silt in the boulder-clay mark the old land surface, and the layers of marine shells which have been or may yet be found in the same deposit, show some of the successive stages in the process of submergence by which that land-surface became by degrees the bed of the sea. We can understand, too, how the boulder-clay, if preserved in this way during its descent, should remain so perfect over such wide tracts of the country. And we are enabled in some degree to explain why the proper marine drift is not more extensively developed, for it probably received but little augmentation during the sinking of the land. Its origin rather dates from the time when the land, freed in part from its mantle of ice, began again to rise from beneath the sea. To the evidence from which the history of this second portion of the Drift period is to be compiled, we must now turn.

II. Re-elevation of the Country: Origin of the Stratified Drift.

The boulder-clay is covered with occasional deposits of sand, gravel, and stratified clay, in which marine organisms are in some places found.[1] As these strata ascend to a considerable height above the sea, it is evident that the land must have been, at least to that extent, submerged below the sea-level. I have already adduced evidence, which seems to render it probable that this depression took place during the accumulation of the boulder-clay. I am not aware that the marine deposits themselves afford any indication of having originated during the sinking of the land, nor indeed is such an indication to be expected. According to the theory which maintains, that while the country was going down beneath the sea, it was covered

[1] I have been greatly at a loss for an intelligible, comprehensive term to express the sands, gravels, and clays which overlie the till. "Stratified Drift," though in most cases applicable, will not always do, for there are instances where this Drift is not stratified. "Marine Drift" is likewise objectionable, for the boulder-clay is in part marine, and moreover, it is by no means certain, that some of the sand and gravel heaps which are classed together in this Drift, have not been produced by freshets on the land. If the word "Drift" had not already been unfortunately used as a general term for the whole of the glacial deposits, it would have served well to denote the upper water-formed beds, "till" or "boulder-clay" being reserved for the lower or ice-formed mass.

over with a wide sheet of ice, the amount of marine denudation would largely depend upon the extent to which the coasts were free of ice, so as to be exposed to the action of the waves. If the cold was so severe as to envelop the island in ice, it must have told not less powerfully upon the sea. Not only would a crust of ice form upon the surface of the salt water, but there would also, in all likelihood, be a thick "ice-foot" along the margin of the land. The waves of the summer storms would thus find comparatively little scope for their ordinary work of demolition, for, save along exposed headlands, they would probably break upon ledges of ice, sometimes upon the protruded mass of a sea-going glacier, sometimes upon the thawing terraces of last year's ice-belt. The chief amount of destruction would be done by the frosts loosening masses of rock, and piling them upon the frozen shelf below. When this rubbish-charged belt was broken up, and carried out to sea, it would drop its burden to the bottom. But this would not be ordinary marine denudation, and the deposits so formed would bear but little resemblance to the great majority of those which constitute what is known as the stratified or marine Drift. It seems to me, that on the whole, the amount of sand, gravel, and stratified clay accumulated by breaker-action during the submergence of the land would not be very great. The boulder-clay was being carried down, platform after platform, beneath the sea-level, and the deposits which might be thrown upon the submerged land would probably consist in large measure of the confused contents of the ice-belt or of drifting bergs, with sometimes sediment of a more ordinary kind derived by the sea, either from the shore rocks, or from exposed parts of the till.

It is on these grounds that I would assign the vast masses of stratified Drift, now to be described, rather to the time of the rising than of the sinking of the land. Whether or not their materials arose in part during the submergence, they would be re-arranged during the re-elevation, and hence, as we see them now, they tell only of an upward movement. When the country went down, it was shielded by a formidable barrier of ice from the constant assaults of the ocean; when it came up again, its protecting bulwark was gone, and its loose covering of rubbish and boulders fell an easy prey to the waves.

The submergence of a large tract of land[1] would tend to ameliorate the climate. Whether this was the main agency concerned, or whether it only coincided with some vast cosmical change affecting the whole planet, and of which as yet we know nothing, is comparatively unimportant in the present inquiry. In whatever way the change was brought about, there can be little doubt, that when the land began once more to rise, the temperature had likewise risen. The ice, in place of thickly covering the whole country, was confined to the upland corries and glens, down which, in the form of local glaciers, it may here and there have reached the sea. And the waves, instead of beating wildly against a cliff of ice, which drove them back from their natural limits, rolled in upon the hummocks of earth and stones which the ice had left behind it, sweeping away mud, sand, and gravel, and spreading them out in wide sheets over the sea bed. Yet the winters seem to have been still severe enough for the formation of coast ice; icebergs, too, probably floated off into the main, while on the land, glaciers filled up many of the deeper and higher valleys; and as the ice and snow which covered the country melted away, sometimes perhaps suddenly, violent floods may have been caused, whereby the detritus was swept out of the glens, and spread out in irregular heaps over the lower grounds. It is the results of all those agencies acting, when the land, though subject perhaps to oscillations of level, was still on the whole ascending, that we have now to consider in the accumulations of Stratified Drift.

Stratified Drift: Difficulty of arranging its members chronologically.—No one who has not made the attempt in the field can be fully aware how extremely difficult it is to ascertain the true order of succession among the members of this part of the Drift series. The general sequence of events may perhaps be understood, but when we come to compare sand-bed with sand-bed, and clay with clay, from different parts of the country, we have really no reliable guide to their relative geological antiquity, or even to the circumstances of their origin. In the case of post-tertiary shore accumulations, it may be assumed as a

[1] The depression seems to have been general over the north of Europe, though probably varying greatly in extent in different regions.

rule that the higher a deposit lies above the present sea-level, the more ancient must be its origin, since in the ascent of a rising land the coast-line of any particular period is constantly receding farther and farther from the sea-margin. Hence, in other words, the older the shore-line the higher will it be found to stand above the sea. Such truly littoral deposits as follow one contour-line round the country may, perhaps, be regarded as in a geological sense contemporaneous, though in the absence of shells it is often impossible to decide whether a series of strata is of littoral origin or not. But it by no means follows either that all superficial marine deposits which lie on the same level are coeval, or that some which are found on a lower platform may not be of the same age with others which occupy a higher site. We know that at present the sand and shingle thrown up daily along the beach are strictly contemporaneous with beds of fine mud and silt that are gathering in stiller water out at sea. Hence a gravel bank on some lonely hill-top far away among the moors and mosses of the inland districts, may have been formed at the same time as beds of fine clay along the sea margin, whereon are built the villages and sea-ports of a busy human population.

The task of collating and arranging the stratified Drift becomes still more dispiriting when we reflect that the ascent of the land would constantly bring up to the tidal zone accumulations that had previously been formed at some distance below the sea-level. Hence there could scarcely fail to be a mingling of deposits which had originated at various depths from the shore-line down to deep water. Further, the action of the waves upon a bank of boulder-clay might reveal some of those little patches of shell-bearing clay which I have described as occasionally occurring in that deposit. Such fine clay-beds, if they escaped destruction, might be covered over with shore detritus in such a way that it would be hardly possible even to suspect that the shell-bed belonged to the boulder-clay and not to the true stratified Drift; to the sinking rather than to the rising of the land. Nor is this all. Though during the growth of the stratified Drift, the country was probably on the whole ascending, there seems no unlikelihood in the supposition that this upward progress was interrupted by long pauses, and even by occasional movements of a retrograde character. Such interchanges would, of course, give the waves still further opportunities for remodelling the previously-formed parts of the Drift, and thus commingling the products of different agents and different periods.

But it is highly probable that the sea has not been the only agent concerned in the production of the loose detritus which covers the face of the country. Part of the sand and gravel mounds may actually indicate the former passage of violent land-floods caused by a rapid melting of the general envelope of ice and snow.

I do not wholly despair that the sands, gravels, and clays of each district will yet be brought into close chronological comparison with those of the rest of the country. But from this consummation Scottish geology is still very far removed. In the meantime more cannot be attempted in the present summary than a general sketch of the nature and position of the stratified Drift. I shall endeavour, however, to preserve so far an approach to the true order of succession, by describing first the deposits which occur in the higher districts, and which, since they have been longest above water, may be most ancient in origin. One or two preliminary remarks may be offered on the relations of the boulder clay and the stratified Drift.

Its relations to the Boulder-clay.—Where the boulder-clay has been wholly washed off a hill-side, we may often trace its former existence there by the occasional striated stones which occur among the loose soil and angular rubbish resulting from the decomposition of the underlying rock. I have observed this fact again and again in the uplands of Peebles and Selkirk. We may thus trace an insensible gradation from good stiff boulder-clay to a loose surface-wash of detritus. Doubtless much of this denudation may be due to the effect of rains, runnels, and larger streams of fresh water. But such agents are far from sufficient to account for the whole of the denudation of the boulder-clay, and the heaps of water-rolled gravel and sand with which it is covered.

So far as my observation guides me, there is a considerably larger area of the country (at least of that part between the

Grampians and the Solway), where the boulder-clay comes up bare to the surface soil, than where it is overlaid with stratified beds. Sometimes it is covered with a re-assorted part of its own mass, and in such cases the two deposits may be seen to shade into each other. But there is usually a sharp line of demarcation between the till and any other bed which overlies it. Often, indeed, the surface of the till is hummocky and irregular, and the sand, gravel, and clay lying on it have been deposited in and over the hollows.

If, passing from such lesser features, we view the relations of these two portions of the Drift over the breadth of the island, we perceive, on reflection, that there is in reality an unconformity between them. The till, as we have seen, clothes the surface of the land from a height of 1700 feet or more down to below the sea-level. It forms a great mantle, sadly worn and ragged indeed, but which, in the parts that remain, accommodates itself to the major undulations and the general declivity of the ground. Now the marine Drift has been deposited more or less horizontally on successive platforms cut out of the till. Instead, therefore, of sloping down to the sea with the descent of the ground, the sands, gravels, and clays lie nearly level upon each other, rising stratum over stratum from underneath the present sea-margin away up to the hill-tops. The beds may thus, for the moment, be regarded as forming horizontal bands, which conform, in a general way, to the configuration of the country. It is evident that along the outer edge of these bands the ends of the strata are truncated by the slope of the ground, and that their inner or landward edge abuts either upon rock or against the mantle of boulder-clay. One of the best examples of this relation which I have seen is on the north shore of the Kyles of Bute, where the stratified clays and sands end off against a slope of boulder-clay. But the same feature may be traced all over the country, even where there are no sections to show diagrammatically the relative position of the various deposits. Here accordingly there is again good evidence that this stratified Drift can have had no immediate connexion with the till.

Mainly derived from waste of Boulder-clay.—That these stratified deposits of clay, sand, and gravel have been in great measure derived from the waste of the old till or debris of the land-ice, is apparent if we compare their pebbles and boulders with those of the latter. The same conclusion is borne out by the fragmentary character of the till, and by the common replacement of this deposit by stratified beds in places where there can be little doubt the till once existed. But the stratified Drift was also in part produced by the action of the waves upon exposed rocky shores, by the sedimentary discharge of rivers or of land floods, and by the detritus carried out to sea by masses of ice. Perhaps, too, there may have been some other agency or combination of agents not yet satisfactorily understood.

Its sporadic Character.—One of the most obvious features of this part of the Drift series, is the local and sporadic character of the beds. It is only in the lower parts of the country, as along the margin of the Firth of Clyde, and in the east of Aberdeenshire, that we meet with persistent beds of clay. In the interior we encounter accumulations, chiefly of gravel and sand, with patches of stratified clay, sometimes gathered together in great masses, and then absent for long intervals. Unlike the old till, therefore, the stratified Drift is far from being distributed with any degree of uniformity over the country. Patches of it in the form of sand mounds, banks of gravel, and sheets of fine clay, resting sometimes on till, sometimes on solid rock, may be seen dotting the country for miles without uniting into one continuous deposit. These are not mere outliers isolated by denudation, for in not a few cases, the stratification of the mounds conforms to their external surface in such a way as to show, that they can have suffered but little from the wasting influences of nature, and that they remain now very much in the same state in which they were left by the sea.

The stratified Drift sinks beneath the sea-level, and ascends for at least 1500 feet above it.[1] It maintains no very definite

[1] In the Ben Muickdhui range, Mr. Jamieson (*Brit. Assoc. Rep.* 1859, Sect. p. 114), has traced beds of drift having all the aspect of a marine deposit up to elevations exceeding 2000 feet. This drift, as was noticed by Sir Charles Lyell in Forfarshire (*Proc. Geol. Soc.* vol. iii.), is more gravelly in texture than that of lower districts ; it also contains fewer, sometimes none, of the striated stones. In the uplands of the southern counties I have never seen stratified drift more than 1500 feet above the sea, and at this height but rarely.

relation to the form of the ground on which it rests. Like the boulder-clay, it is on the whole most abundant in the main valleys, but occurs also on the sides and summits of the hills. It spreads out over a wide area in the basin of the Firth of Clyde. There, however, and in some other maritime tracts, it presents features which are not seen, or at least only partially, in the interior. The fine clays of the Clyde probably belong to the latest stages of the Drift period; the sand and gravel mounds of the interior seem to be of older date. In accordance with the plan above proposed, I shall first describe the general character of the stratified Drift of the interior of the country, and then those of the lower districts. This arrangement, however, though it has a show of chronological order, must be confessed to be more one of convenience than of any well-founded systematic division.

1. *Stratified Drift of the Interior.*

Let the geologist conceive an undulating country with its valleys and hill slopes thickly covered with boulder-clay, or gravelly detritus, from which the bare rock either protrudes in knolls along the sides and summits of the hills, or rises above the plains into steep crags and isolated eminences. Let him imagine these valleys to be still further choked up here and there with mounds of shingle and sand, and the hill-sides to be dotted over at wide intervals with long banks and patches of the same material. Let him picture these banks and mounds running over wide moors, with now and then basins of fine clay, derived from the waste of the underlying till, and he will have some idea of the general disposition of the Drift throughout large tracts of Scotland.

As an illustration of the development of the marine Drift along the wider valleys, I may instance the great central valley of the country between the Clyde and the Firth of Forth. On the north side of the latter estuary it occurs as a chain of sand and gravel hills, extending from Largo Law up the valley of the Leven to the lake of that name, whence it stretches westward into the Vale of Devon. On the south side it occurs throughout the Lothians in endless hillocks of gravel and sand and local patches of brick-clay. The deposits of sand and gravel are enormously abundant between Linlithgow and Falkirk. They likewise run westward in patches beyond Midcalder, and reappear on the west side of the water-shed of the country in a series of long sinuous ridges, which extends for miles across the Carnwath moors, and thence descends into the vale of the Clyde.

In many of the Highland valleys and glens, mounds and ridges of well-rolled gravel and sand likewise occur, often far removed above the present channels of the streams. Accumulations of this kind were observed by myself up the valley of the Dee to Balmoral, and they have been traced by Mr. Jamieson in detail all along the same valley, as well as along the Don, the Ythan, the Deveron, the Findhorn, the Spey, the Tummel, and the Tay. He finds, that in some cases the gravel shows an arrangement of its pebbles that appears to indicate the former existence of a current sweeping down the glens, a circumstance which is further indicated by the arrangement of the detritus in long ridges behind the lower ends of knobs of rock which look up the glens.

In more confined valleys the same prevalence of this sandy and gravelly drift is observable. Thus the depressions in which flow the Tweed and its tributaries, as the Biggar, Tarth, Lyne, and Eddleston Waters, are full of masses of water-worn detritus rising far out of reach of the present streams. The valley of the Clyde also, from where it leaves the Silurian uplands, is for several miles dotted over, sometimes almost barred across, with mounds and ridges of sand and gravel.

But the stratified Drift is by no means confined to valleys. It may be found in patches on the sides, and even on the summits of hills. Thus along the eastern flanks of the Lamberton Hills, between Berwick-upon Tweed and Burnmouth, irregular mounds and coalescing ridges of gravel reach a height of 350 feet above the sea. Such ridges are abundant along the sides of the Lammermuirs and Pentlands, where there is no higher ground between them and the opposite sea. Some interesting examples likewise occur round the flanks of Tinto, especially on the north side. Again, in Aberdeenshire, Mr. Jamieson has described a mass of water-worn shingle covering the top of a ridge of hills which extend from Buchan Ness for seven or eight miles inland, till they attain a height of 464 feet above the sea.[1] The same observer has traced stratified silt, believed by him to be marine, up to a height of 1550 feet on the flanks of Meal-Uaine in Perthshire.[2] A patch of gravel likewise occurs at a height of 1500 feet on Craigengar, one of the Pentland Hills. Stratified gravel and sand have been found by Mr. Jamieson, even as high as nearly 2000 feet in the Braemar mountains. But it seems doubtful if these are marine. No marine organisms have been found in any part of the Scottish Drift higher than 510 feet above the sea. The extreme height to which true marine Drift ascends has still to be fixed.

Even on the water-shed of the country, masses of stratified Drift may be found. Thus, between the Clyde and the Tweed at Biggar, there is a valley (650 feet over the sea) scarcely elevated above the level of the former river, and dotted over with heaps of sand and gravel, which rise high on the sides of the surrounding hills. The same feature is seen at Garvald and Dolphinton, where the ground which divides the Medwin (a tributary of the Clyde) from the Tarth (an affluent of the Tweed), at the height of between 700 and 800 feet above the sea-level, abounds in hills of fine white stratified sand. Up to nearly the crest of the ridge, between the sources of the Yarrow and the Moffat Water, rounded shingle may be traced to a height of 1000 feet above the sea.

Its Composition.—This division of the Drift is far less uniform in character than the boulder-clay, and presents no such intimate relation to the nature of the rocks on which it lies. It consists entirely of water-worn sediment, varying in texture from the coarsest shingle to the finest clay. It is usually stratified, but is singularly destitute of fossils. The coarser parts are sometimes devoid of any structure, and are piled together in ridges, mounds, and hillocks, like banks of gravel cast up by storms. But it is probably seldom that traces of stratification will not

[1] *Quart. Jour. Geol. Soc.* vol. xiv. [2] *Op. cit.* vol. xvi. p. 362.

be found in some parts of these ridges. The coarse gravel is often interstratified with bands of sand, and the various beds go on interlacing with each other in endless lenticular layers. The sand is frequently full of diagonal lamination, and here and there contains a huge boulder where there is not perhaps another stone so large as a hazel-nut. Masses of pure white sand form groups of hillocks and ridges, as at Markinch in Fife, Mendick Hill in Peeblesshire, and Carstairs in Lanarkshire. With these deposits are occasionally associated thin beds and laminæ of clay, of a dull red, olive, or drab colour. Stratified clay, in thicker deposits, likewise occurs in hollows of the till, and is the common source which supplies our inland brick-works. It is usually devoid of stones; but in some places it contains them in such abundance as to approach in general aspect to the old till.

The nature of these strata can be advantageously studied in the Vale of the Clyde, and on the moory district between the town of Lanark and the border of Mid-Lothian. The river Clyde has cut through some deep masses of it in the neighbourhood of Carstairs, and exposed their structure in a line of cliff which is changing with every winter. The finely-stratified false-bedded appearance of the sands, the lamination of the clays, and the frequency with which these deposits are intercalated with each other, have been well brought to view by the operations of the river. A more careful search will show that some of the clay bands contain numerous stones, sometimes angular, and with one or more sides covered with striations. At Carstairs, the fine sand-beds of the railway cutting contain two or three large blocks of stone; and some of equal size, which have probably come out of the sand, may be seen on the margin of the Clyde, at the bend nearest Carnwath. In such cases, it is plain that the current, which gave rise to the fine lamination and counter-bedding of the sands, must have been wholly inadequate to the transportation of such large masses of rock. On the other hand, a body of water, which could hurry along these boulders, would assuredly have swept away the sand. The boulders must have been brought by some other agency—either that of coast-ice or of bergs. The existence of ice at the period of the deposition of these strata is still further shown by the scratched stones in the beds of clay, and by a remarkable contortion of the strata, to be immediately described.

The stratified Drift, in place of being spread over the surface of the country in a more or less persistent sheet, is gathered up into patches, sometimes of very limited extent, and sometimes covering an area of many square miles. Where it consists chiefly of sand or gravel, as it does over the greater part of the central valley, from the Firth of Clyde to the mouths of the Forth and Tay, it shows a remarkable arrangement into long confluent ridges, or into detached conical tumuli and hillocks. The resemblance of such cones of drifted sand and gravel to artificial mounds is so strong, that they are very generally regarded as true sepulchral heaps. But the stratified, and often diagonally laminated character of the sand, is sufficient proof that man has not had a share in their construction. That the mounds, however, have been used as places of burial does not admit of doubt. They are known in the Highlands as *tomhans*, the dwellings of a fairy race.[1] The long ridges are called in Scotland *Kames*, and are well exhibited in many parts of the Lowlands, as near Dunse in Berwick-

[1] Mr. Chambers in his *Ancient Sea Margins* satisfactorily shows that the mounds of Dunipace—so fruitful a source of conjecture to the antiquary—are of natural origin. It may serve to indicate, however, how strange and artificial is the aspect of such mounds of stratified Drift, that we find them everywhere regarded as the work of some earlier race of men or spirits. I could enumerate several instances where the existence of hills and ridges of sand in the south of Scotland has been for many generations popularly ascribed to the agency of Michael Scott, and his band of tributary imps. On the flanks of the Eildon Hills, for example, there is a series of sand ridges, such as are described in the text under the name of *Kames*. They are thus explained. A certain restless spirit had given the wizard no little trouble. He had to be kept in constant employment, and performed in this way the most marvellous feats, such as cleaving the Eildons in a single night. At last, Michael commissioned him to make ropes out of sand; but this task proved more than he could accomplish. He succeeded, indeed, in arranging the sand in long lines like the strands of a rope, but these fell in showers the moment he attempted to raise and twist them round each other. And to this day we see the lines of sand running down the hill-side, some of them broken and effaced where the hapless spirit had fruitlessly tried to entwine them.* Scott alludes to this tradition in Note Z to the *Lay of the Last Minstrel*.

shire, at Loanhead in Mid-Lothian, in the Clyde Valley at Thankerton, and in Fife down the Vale of Leven. They occur also in Aberdeenshire. But the most wonderful display of them which I have yet seen lies in the moory tract of Lanarkshire, between Cleghorn and Auchengray.

Kames.—These curious ridges appear to be identical with the *ösar* of Sweden and the *eskers* of Ireland.[1] Considerable misapprehension has existed as to their structure, and hence some wholly untenable explanations have been offered as to their origin. They have been compared, for example, to moraines, and have been regarded as the traces of vanished glaciers. But this hypothesis is at once disproved by the situations which they frequently occupy in the middle of wide moors out of the reach of any glacier, by the water-rolled nature of their contents, and above all, by the fact that they are almost always stratified.

A kame may be described as a ridge of gravel or sand running in a more or less sinuous line, from a few yards to several miles in length, averaging perhaps from thirty or forty to fifty or sixty feet in height, and rising abruptly from the ground into a narrow crest. Such a ridge is often seen alone with no other mounds or ridges of detritus near it, keeping its course across a heathy flat like an artificial dam or rampart, and conspicuous from a distance not only by its form and size, but by the greenness of its slopes contrasting with the brown of the surrounding moor. I have never been able to trace any definite and persistent relation of these ridges to the form of the ground on which they occur.[2] Sometimes, as on the north flank of Tinto, the ridge begins on a hill-slope, and extends away into the plain. Sometimes it runs parallel to the hill-side, as below the west front of the beautiful cone of Quothquhan, near Thankerton. Again, it may be seen rising up in a flat moor apart from any rising ground, as is admirably

[1] See Sir Charles Lyell, Paper on the Scandinavian Osar, *Phil. Trans.* 1835, p. 15, and Mr. Jukes on the Irish Eskers, in the second edition of his *Manual*.

[2] Mr. Milne-Home remarks that in the east of Scotland the kames have a general east and west direction, *Brit. Assoc. Rep.* 1861, p. 115. But I could cite not a few examples where the direction is more north and south.

shown on the Carnwath moors, and on those to the south of Dirrington Law in Berwickshire. I have frequently observed, however, that these ridges run across valleys, and have been cut through by the streams. Examples may be seen in the Clyde Valley at Thankerton, and at the junction of the Douglas Water, in the course of the Mouse Water (a tributary of the Clyde) near Ravenstruther, in the grounds of Dunse Castle, on the moors between Dunse and Westruther, and in many other localities. Yet other instances might be cited where the kames run along the line of the valley, especially if it be a wide and tolerably flat one. This may be verified in the course of the Medwin above Ogscastle, and on a much greater scale in the wide valley traversed by the Caledonian Railway between Auchengray and Carstairs. When we consider the nature of their contents, it seems hardly possible that these ridges have no dependence upon the form of the ground. I believe there must be some general relation which has hitherto escaped observation, but which, when discovered, will be found to connect them satisfactorily together.

But the kames are not always solitary mounds. In some districts they ramify into different branches, often coming together again so as to form basins, which, having for the most part no outlet at the surface, are either the site of peaty marshes, or of small lakes. This form of ground is illustrated in a remarkable manner round Carstairs. A well-formed kame begins in the moors beyond Carnwath, and, after running for upwards of two miles in a sinuous course, with here and there a short spur running out on either side, and with one or two lateral basins, merges into a group of confluent ridges, which continue in the same direction for more than three miles farther. Those

FIG. 4.—Sectional outline of sand and gravel mounds at Carstairs, Lanarkshire. (The dark layers in the hollows are deposits of peat.)

ridges are connected together by transverse bars at irregular intervals. Hence there results a net-work of anastomosing sand bars and mounds, enclosing an endless succession of basins, from two or three feet, up to two or three hundred yards in diameter, and their bottoms sometimes sixty or eighty feet below the crest of the surrounding ridge. These hollows are, in three or four instances, occupied by water; more commonly a flat, peaty bottom marks where an ancient lochan has been. They lie at many different levels in the range of sand mounds; indeed, in this respect they appear to be each independent of the others. It is a singular scene which lies spread out before the observer when he places himself on one of the higher eminences among this rolling group of hills. Here and there his eye rests on the dark peaty hollows, from which the green grass-covered mounds rise up sharply, and sweep away to the north-east in undulating succession. Beneath him, perhaps, lies the solitary little tarn called the White Loch, its sides as steep and circular as one of the crater-lakes of the Eifel. Far away to the north and west stretches a wide flat moor, from which the sand-hills start up like lines of rampart. He feels that somehow it is but the model in miniature of a great mountain scene on which he is looking. The lines of valley, the lakes, the deep enclosed corries, the lonely moorlands, and the rolling hills are all there, but they are dwarfed into a pigmy size.

A kame consists almost entirely of sand or gravel, varying in texture from the finest grain up to a coarse aggregate of boulders. These materials, except in rare cases, are stratified. They often alternate with each other in rapid succession; thin layers or laminæ of sand are intercalated in the gravel beds, and occasional seams of gravel vary the stratification of the well-bedded masses of sand. The sands, moreover, are as a rule full of diagonal lamination or current bedding. It seems plain, therefore, that currents of water must have played some part in the accumulation of these sedimentary deposits. This is still further shown by the occasional introduction of thin lenticular seams of laminated clay.

In Lanarkshire, I have found two well-marked classes of kames—1*st*, Those which consist wholly, or nearly so, of coarse shingle; and 2*d*, Those that are made up of fine sand and gravel. The shingle kames are usually sharper and higher in outline than the others. Their component gravel is either stratified very rudely, or not at all. The stones are usually well rounded, and vary in size up to blocks four or five feet in length, which, in one or two instances, I found polished and striated. The striæ, however, were less sharply retained than upon stones in the boulder-clay. A good illustration of this form of kame is shown in the neighbourhood of Carstairs, where the Mouse Water has cut through a long sharp ridge of gravel, and laid bare a section of it on both sides of a broad water-course. The eastern bank is a high steep cliff formed by the cutting through of the kame. A mass of very coarse unstratified well-rounded gravel is there laid open, rising up into the conical mound which makes the kame, and overlaid on its south side by a series of finely-laminated clays and sandy beds. These latter strata point to a time of quiet deposition, for the clay splits up into thin layers like the leaves of a book. They rest against the slope of the shingle bank, which thus seems to have undergone little alteration since the time of their deposition. The mode of accumulation of the gravel, however, is a question of no little difficulty. That ice has been in some way or other concerned in the process, I do not doubt. The mere striation of the stones seems to place this beyond dispute. The size of some of the blocks, too, favours the idea that they were helped along by the carrying power of ice. Moreover, on the west side of the river, the same ridge of coarse gravel shows here and there in its mass thin layers of sand, and at least one lenticular seam of fine olive-coloured clay. Had the heaping together of such blocks been done by the transporting agency of a powerful current, or by a set of strong tides, we might expect that there would have been some definite arrangement of the whole mass in lines of bedding. It is not easy to see how, by such agencies alone, the gravel should have been huddled tumultuously together, with here and there nests and layers of stratified sand and clay. When the true solution of the origin of these perplexing ridges is discovered, we shall probably find it a complex one, involving the operation not only of the tides and currents of the sea, but of drifting ice; perhaps, too, in some cases, of the floods caused by melting snows, and possibly of some other agent whose concurrence we do not at present suspect.

The second form of kame consists of mounds of sand, or of sand and gravel in well-stratified beds. These strata present a convex or dome-shaped arrangement; they are heaped over a central nucleus of the same materials, and it is the upper

FIG. 5.—Section of a Kame laid open on the line of the Lanark and Douglas Railway.

surface of the outer bed which defines the outline of the Kame. Where this outer bed consists of a layer of gravel, the ridge is usually sharper and better preserved than where loose sand has formed the surface. Thin beds of clay, sometimes finely laminated, are occasionally to be observed even among the densest masses of sand and gravel. Neither in these clays nor sands has any trace of an organism yet been found. Some interesting sections have recently been exposed through this series of Drift-beds, by a cutting of the branch railway from Cleghorn to Douglas. But I reserve a full description of them for a future number of the *Memoirs of the Geological Survey.*

The perfect stratification and diagonal arrangement of the sand in this form of kame, the minuteness of lamination in the occasional clay-seams, and the grouping of the whole series of layers, one over the other, into a conical mound, seem to disprove any hypothesis which would explain these ridges as the result of a violent rush of water.[1] These structural characters rather indicate a slow and long-continued process, in which currents from different quarters, and laden with various kinds of detritus, took a large share. Two currents coming from opposite directions, and each charged with sediment, would deposit a part of their burden along the line of their junction. But it is often difficult to understand from the existing form of the ground where the

[1] See, for example, Mr. Milne-Home, *Rep. Brit. Assoc.* 1861, p. 151.

kames occur, how two such currents could have been produced, and how, above all, they should have dropped their loads in such places as we now find the kames to occupy.

The kames, whether of unstratified shingle, or of well-bedded gravel and sand, merge imperceptibly into a wide expanse of undulating ground, the uneven surface of which results from the unequal deposition of the same materials of which the more marked ridges or kames are formed. It is, in short, a tract of gravelly and sandy detritus, which is in some parts heaped up into long well-defined mounds.

Brick-clays.—These occur usually in hollows of the boulder-clay, and coincide in colour with the local changes which that deposit undergoes. They are usually well stratified, the layers being sometimes as fine as the leaves of a book. Though commonly to a large extent free from stones, they here and there contain them in such quantities as to approach in general aspect to the old boulder-clay. These stones, moreover, are occasionally striated, and it is sometimes possible to follow them to their original sources.

In the interior of the country I have never been able to trace these clays, except over very limited areas. Along some of the lower or maritime districts, however, as will be pointed out in the succeeding pages, they appear to have been deposited in much more continuous sheets. In these localities, too, they have yielded molluscan remains in abundance, but in the inland districts, so far as I am aware, they have not yet afforded an organism of any kind.[1]

The brick-clays may be found interstratified with the Kame group of beds; the whole forms therefore one series of deposits.

[1] Mr. Milne-Home, in his paper on the Parallel Roads of Lochaber (*Trans. Roy. Soc. Edin.* vol. xvi.), mentions the occurrence of a bed of peat one foot thick, with imbedded roots of trees resting on a fine silt, and covered by ten feet of sand. This deposit was seen in a railway cutting between Edinburgh and Newhaven, and lay between seventy and eighty feet above the sea. It is uncertain whether or not it should be classed with the drift now under review. Possibly when the land stood seventy or eighty feet lower than now, the peat was forming close to the shore, and was buried beneath a mass of sand driven up either by the waves or by the winds. Mr. Milne-Home mentions that the peat contained roots apparently of the hazel, with stems of reeds and other marsh plants, and seeds like those of a species of whin.

In some localities where this union of sands and fine clays is exhibited, there occur some of these curious contortions of the bedding which are characteristic of the Drift of the Norfolk coast.

Contorted Bedding.—Sir Charles Lyell was the first to observe the occurrence of contorted beds in the stratified Drift. Between the South Esk and the Prosen, some stratified gravels and sands were found by him to be so disturbed, that a perpendicular shaft might intersect the same beds three times. The red boulder-clay below had not suffered, and some of the contorted beds were overtopped by others perfectly horizontal, showing that the disturbance took place during the deposition of this series of strata.[1] The best illustration with which I am acquainted, is one which may be seen on the north bank of the South Medwin Water, a short distance above the confluence of that stream with the Clyde. Its features will be understood from the accompanying figure. The bed of stony clay on the

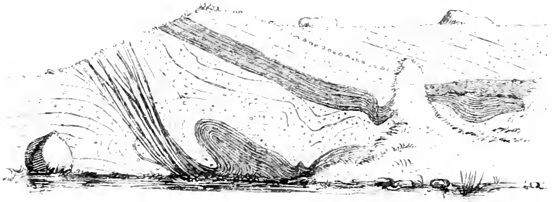

FIG. 6.—Section of contorted beds of sand and clay. Medwin Water.

right-hand side of the section, presents several points of interest. Its enclosed stones are subangular and rounded; they vary in size up to a foot or eighteen inches in length, and abound in striated surfaces. The great majority of them consists of various felstones, with some pieces of Silurian grit—rocks which are found in places immediately to the south, on the high grounds that rise from the south side of the valley of the Medwin. The locality of the felstone is unmistakable. These scratched

[1] *Proc. Geol. Soc.* vol. iii. p. 341.

stones must then have been transported from the hills above Biggar across the Medwin valley. I am by no means sure, however, that this layer of stony clay is not a cake of the true till, which, frozen into a mass of ice on the Biggar hills, was borne across the sea-strait that once covered the low grounds of the Medwin, until it was dropped on the spot where we now find it. But in whatever way they were carried, the course of the stones was certainly northward, and the place of their departure can still be approximately fixed. Nor is this all. Here and there over the surface, and sometimes in the interior of the mounds of drift, of which the preceding woodcut gives a section, large blocks of a red pebbly sandstone or fine conglomerate may be seen. These are so altogether out of proportion to the little pebbles which the sand-beds contain, that they plainly do not owe their transport to the ordinary drifting operations of marine currents. They too must have been ice-borne. Nor do we require to look far for their source. Not much more than a mile to the north-east, there is a long bare hill, to which allusion has been made on a previous page, composed of the same Old Red pebbly sandstone and conglomerate, which protrudes at many places in loose blocks of all sizes. I do not doubt, that when the land stood about 800 feet lower than it does at present, coast-ice formed in sheets along the sides of this hill, and that masses of it, into which blocks of the rock had been frozen were broken off, and carried their burden over the sand-mounds to the south-west.

The striated boulders of the stony clay and the large blocks on the surface, bear each their testimony to the former presence of ice-rafts which drifted across from the high grounds on the south and north sides of the strait. The crumpled appearance of the strata depicted in the figure corroborates this testimony. The fine beds of clay, fairly bent back upon each other, may be traced curving round into a sharp loop, and then into another equally abrupt, after which they go waving along until they are lost under a mass of turf and debris. A line perpendicular to their plane of bedding, would thus, in the course of two or three feet, intersect them thrice at nearly a right angle. Such contortion must be due to powerful pressure. It may have been produced by a mass or masses of ice standing here and pushed onward for some way over the yielding sand, partly by their own impetus, partly by the action of winds or currents. The compression to which such a weight of ice would give rise, would probably be quite sufficient to corrugate beds of clay and sand, of which the cohesion could not be great.[1]

Erratic Blocks.—Scattered over the surface of the country, sometimes on the bare rock, sometimes on the boulder-clay, and sometimes either on or in the stratified Drift, are numerous blocks of stone which do not belong to the rocks immediately around them, but which have been carried from greater or less distances.[2] It is a common error to associate these blocks with the boulder-clay, and consequently to speak of that deposit as an erratic one. But I have already shown that the stones of the boulder-clay, in the vast majority of cases, have not been derived from any other rocks than those of the surrounding district. The blocks now to be described are to be considered as contemporaneous in their transport with the deposition of the stratified Drift. They belong to a time when the present land was in great measure beneath the sea, when glaciers still lodged in the recesses of the mountains and descended to the sea-level, and when bergs and coast-ice, drifting over the submerged hills and valleys, carried away the blocks of one district and dropped them upon another, perhaps fifty or sixty miles distant. Hence, though such boulders are most obtru-

[1] See Lyell, *Proc. Geol. Soc.* vol. iii. p. 171.

[2] There are some districts where the number and size of the erratics have given rise to the wildest legends of warlocks and elfins. Such a locality occurs between Carnwath and the river Clyde. Here, before farming operations were carried to the extent to which they have now arrived, large boulders, now mostly removed, were scattered so abundantly over the mossy tract between the river and the Yelping Craig, about two miles to the east, that one place was known familiarly as "Hell-stanes Gate" [road], and another "Hell-stanes Loan." The traditional story ran that the stones had been brought by supernatural agency from the Yelping Craigs. Michael Scott and the devil, it appears, had entered into a compact with a band of witches to dam the Clyde. It was one of the conditions of the agreement that the name of the Supreme Being should never on any account be mentioned. All went well for a while, some of the stronger spirits having brought their burden of boulders to within a few yards from the river, when one of the younger members of the company, staggering under the weight of a huge block of greenstone, exclaimed, "O Lord, but I'm tired." Instantly every boulder tumbled to the ground, nor could witch, warlock, or devil move a single stone one yard further. And there the blocks lay for many a long century, until the rapacious farmers quarried them away for dykes and road-metal.

sively seen when lying on the surface of the ground, especially along a bare heathy hill-side, they may also be found occasionally imbedded among the stratified sands and clays which were formed during the same period of submergence. Examples of this kind have just been given, and others will be cited from the stratified Drift of the maritime districts. It would indeed be easy to multiply such proofs that the true erratic blocks which are strewn over the country must not be classed with the boulder-clay, but with the deposition of the stratified Drift. The transporting agents have not been glaciers, but masses of ice borne across the sea.

These erratics are not thrown down wholly at random across the face of the island. It is easy to trace, that in at least some districts they have radiated from the main mountain masses towards the plains. Thus, to the south-east of the chain of the Grampians, blocks of mica-schist, clay-slate, gneiss, and granite, may be followed sometimes for fully fifty miles. If we glance at a map of Scotland we see that the south-eastern margin of these mountains descends into a wide valley, on the further side of which runs the line of the Sidlaw, Ochil, and Lennox hills. Now this chain of heights has intercepted a large number of the rock-laden masses of ice which were carried out from the Grampian shores. The blocks are found in great abundance along the north-west fronts of the hills, that being, of course, the side which faced the direction whence the bergs came. Sir Charles Lyell has described some striking examples from the Sidlaw range. Thus, on Pitscanly Hill, at a height of about 660 feet above the sea, he found a block of mica-slate thirteen feet long, seven broad, and seven in height, above the ground. One of the nearest points at which the rock occurs *in situ* is fifteen miles distant, and between the localities intervenes the great valley of Strathmore, and the hills of Finhaven.[1]

But some of the bergs appear to have found their way, either across this range of hills, when it may have been in great part or wholly submerged, or through gaps such as that at Stirling in which flows the Forth. Blocks of some of the metamorphic rocks of the Highlands have been observed on the flanks of the Pentland Hills. One described by Mr. Maclaren, stands about

[1] *Proc. Geol. Soc.* vol. iii. p. 344.

1020 feet above the sea, and may be computed to weigh about eight or ten tons. In the same neighbourhood I have noticed some smaller blocks of white quartz-rock. According to Professor Nicol, similar erratics have even been seen on some of the Silurian uplands of Peeblesshire. These boulders cannot have travelled less than fifty or sixty miles. They must have been carried from the Highland mountains, either through or over the range of the Lennox and Ochil hills, and across the deep valley of the Forth.

Mr. Hopkins has observed a similar dispersion of erratics from the high grounds round Ben Cruachan.[1] He found blocks of granite in the beach at Oban, and in considerable mass to the northern extremity of the island of Kerrera. A large number of similar boulders occur on the shores of Loch Lomond, Loch Long, and Loch Fyne. These, he supposed, might have come from a granitic tract in the immediate vicinity of Loch Sloy, at an elevation of from 1500 to 2000 feet. They are dispersed along the sides of the valleys to the height of 300 or 400 feet. One large boulder of granite may be seen much farther to the south, on the shore of Bute, near the Point of Ardmaleesh. I am not aware of any granite from which this block could have come nearer than that of Ben Cruachan, which is thirty-five or forty miles off in a straight line, with several intervening deep valleys, such as that of Loch Fyne, and some ranges of high ground including the mountainous tracts of Cowal.

The erratics of Bute have all come from a northerly source. On the slate hills of that island blocks of mica-schist, quartzose grit, and gnarled gneiss are not unfrequent,—all these rocks occurring in great mountain-masses a few miles to the north. The direction of transport, however, is still more convincingly shown upon the southern half of the island, which consists of red sandstone, with some outliers of igneous rock. Over this tract blocks from the metamorphic regions to the north are profusely scattered, but a fragment of sandstone is never, I believe, found to the north in the slaty and schistose districts.

The beautiful valley of the Girvan at Dailly is strewn with

[1] Reports of *Brit. Assoc.* for 1850, and *Edin. New Phil. Jour.* vol. xlix. 334, vol. liii. 362.

blocks of granite. These may have come across from Arran, though it is perhaps more probable that they were brought down from the granite tracts of Galloway, which stretch away southward from lonely Loch Doon. The granite of Criffel is found a long way to the south among the boulder Drift of the northern and western counties of England.

I need not multiply instances of a phenomenon so familiar. They may be found in almost every part of the country. There are one or two additional points of interest, however, connected with the dispersion of erratics, to which a brief reference may be made.

In the first place, it is occasionally possible to trace these blocks for some distance in lines, as if they had been dropped at intervals by a mass of ice which was moving steadily in one direction. Sir Charles Lyell has referred to a continuous stream of boulders and pebbles, traceable from near Dunkeld by Cupar and Forfar, to the sea at Lunan Bay—a distance of nearly forty miles.[1] On the Pentland Hills, Professor Nicol thought he could trace the erratics in "broad bands, running nearly in straight lines, from NNW to SSE, without any reference to the present declivity of the ground."[2] A beautiful example of the same kind may be seen on the crest of Cairngryfe Hill to the north of Tinto. This ground is probably not less than 1000 feet above the sea. The hill runs as a long ridge in a NE and SW direction, and shows, in many places, its pink felspar-porphyry protruding from under a scanty covering of turf. Over this bare surface run two lines of blocks of hard white sandstone. These stones vary in size, from a mass containing fifteen, to one comprising forty cubic feet. Hence they may be assumed to average about two or three tons in weight. There is no rock like this for many miles round. It is evidently a carboniferous sandstone, yet the blocks are at a much higher level than any of the carboniferous rocks of the surrounding districts. When I found these erratics, I felt considerably at a loss to account for their position and to guess at their source. Before I quitted the hill top, however, a distant

[1] *Proc. Geol. Soc.* iii. p. 342. This instance, however, may perhaps more fitly be classed with some of the phenomena of the kames.

[2] *Quart. Jour. Geol. Soc.* vol. v. p. 22.

gleam of sunlight fell over the uplands of Ayrshire, and brought out in relief, against the western sky, the summit of Cairn Table, which rises nearly 2000 feet above the sea. I was familiar with the peculiar white quartzose sandstone forming the upper part of that hill, and on looking again at the texture of the erratics, I was struck with their resemblance to the Ayrshire stone. The distance of the two localities is about 17 miles, in a north-east and south-west line. A few days later, on again crossing this line, a few miles to the south-west of Cairngryfe Hill, I found another irregular stream of similar blocks. It seems to me highly probable, therefore, that these fragments of hard white sandstone have been ice-drifted from the high grounds round the sources of the Ayr, and carried in a north-easterly direction so as to be dropped in long lines over the moors and hills of Carmichael.

Another question of not a little interest is the height to which erratics ascend above the present sea-level. Mr. Jamieson mentions that in Braemar he has seen transported boulders on hill-tops more than 3000 feet in height, and in Perthshire up to elevations exceeding 2000 feet. He regarded these at the time as having probably been carried by drifting ice. If this be their true explanation, it follows, of course, that the land during its submergence must have been 3000 feet lower than it is now. But it is, perhaps, possible that these blocks may have been transported from one hill to another by land-ice during the general glaciation of the country. Although foreign fragments occur up to a height of 3000 feet, none are found on the tops of the granite mountains of the Ben Muic Dhui group, which attain elevations approaching 4000 feet.[1] This, of course, does not prove that these high grounds were not submerged, but it harmonizes well with the supposition that they were wrapped in a mantle of ice which spread over the hills of lesser height, and bore onwards the blocks which fell upon its surface from such precipices as that of Lochnagar. Again, near the top of Tinto, which is more than 2300 feet high, I have found pieces of carboniferous sandstone and greenstone; but these, I do not doubt, are relics of the boulder-clay. They are all small, and are mixed with abundant fragments of the red felstone of the

[1] Jamieson, *Quart. Jour. Geol. Soc.* xvi. 367.

hill and the dull reddish or greenish grits and conglomerates of the district.

There is no question connected with the deposition of the marine Drift which more requires a careful investigation than the extent to which the land was submerged during that part of the glacial period. That all the ground below 2000 feet was under water I think highly probable. With regard to higher elevations, though I am very far from denying their submergence, I do not think any satisfactory proof of the fact has been yet put on record. Mr. Jamieson will, I trust, before long be able to put this matter definitely at rest.

Lastly, erratics are sometimes found at a considerably greater altitude than the rock from which they have been derived. It is possible, indeed, that some of the recorded instances may be referrible rather to the time of the general glaciation than to that of floating bergs. Thus boulders in the till, or lying on the surface but evidently washed out of that deposit, I have often found at higher elevations than their parent rock. The motion of a great sheet of land ice from the higher parts of the country to the sea would be sufficient to carry such boulders down into valleys and up again to the tops of such hills as were enveloped beneath the icy flow. But in the case of large angular erratics, more especially such as lie upon stratified Drift high above their original source, the most probable explanation is that which supposes that they were drifted about from coast to coast during a depression of the land, or that they were pushed up above high-water mark by the grinding of the floes, that they thus remained at the sea-level while their parent mass was carried down below it, and that they were finally stranded, and thus when the land rose again they lay far above their original site. Such a hypothesis would involve oscillations of level during the general movement of upheaval which characterized the epoch of the marine Drift. This, therefore, is a subject which well deserves the renewed attention of geologists.[1]

Origin of the Sandy and Gravelly Drift.—Before quitting the subject of the Drift of the interior of the country, some remarks may be offered upon the circumstances under which it was formed. I have already stated the probability that its accumu-

[1] See Darwin, *Quart. Jour. Geol. Soc.* iv. 315, and the authorities cited by him.

lation went on during the re-elevation of the land, and that coast-ice must often have had a share in transporting at least the heavier parts of its contents. I believe the greater part of this Drift, though it is unfossiliferous, to be of marine origin. Its occurrence on water-sheds, or on the sides of mountains and hills far out of reach of any stream, seems sufficient evidence that in such cases fluviatile action must have been impossible. And in these situations the mounds of sand and gravel are exactly comparable with others which occur in lower parts of the country. It is difficult, therefore, to avoid regarding the whole as due to the operation of some one general agency. This agency was, in all likelihood, the waters of the ocean.

It may, perhaps, be possible eventually to show that there are certain levels at which the amount of stratified Drift is much greater than at others. If a persistent band of sand and shingle could be traced at one general height round the island, it would afford good evidence of a long pause in the upheaval of the land. Something of this kind seems to be indicated by the masses of sand and gravel which wind round the base of the hills on the confines of the counties of Peebles and Lanark from Dolphinton southwards to the water-shed between the Clyde and the Tweed. The sand-hills between Mendick Hill and Dolphinton reach a height of about 900 feet; those lining the hollow between the Clyde at Symington and the Tweed at Rachan ascend the slopes to a height of 820 feet. The wide range of sand and gravel ridges on the Carnwath moors are between 700 and 800 feet above the sea. But this district is at present under investigation by the Geological Survey, and this point will be examined in the course of the ensuing summer. Such traces of actual sedimentary deposits along well-defined contour lines would be more satisfactory evidence of pauses during the rise of the land than evanescent terraces of erosion, which, being only well marked close to the sea-margin, become fainter as they ascend above that level. Such terraces depend, for their prominence, partly upon the nature of the material opposed to the action of the waves, partly also upon the length of time during which they have been subjected to that action. The non-existence of the terraces, therefore, would by no means invalidate the conclusion as to a general submergence of the land. It might merely indicate that the upheaval had been comparatively rapid, or had not been marked by long pauses at successive elevations. Again, the greater distinctness of one terrace as compared with others, cannot of itself be regarded as proving a longer sojourn of the sea-margin at that particular level. The prominence might be due as much to the recentness of the uprise, or to the nature of the material, whether Drift or rock, acted upon by the breakers, or to the absence of runnels and streams by which the terrace might have been more or less effaced. Mr. Chambers has ingeniously traced a number of lines along the surface of the island which he regards as marking successive pauses during the re-emergence of the land.[1] The evidence for the identity of these lines with ancient beaches would be more satisfactory if they were more frequently found to retain traces of littoral deposits.

The deposition of the marine Drift would be greatly affected by the manner in which the land rose. If this elevation proceeded by slow stages, separated by long pauses, there would be produced the lines of old beach just referred to. If there were no pauses, these lines would be absent, and the Drift would be scattered over the surface as it was left by the retreating tides. If, on the other hand, the rise proceeded by jerks or sudden uplifts, the backward recoil of water would undoubtedly produce powerful effects in sweeping away loose detritus, and heaping it up in sheltered places, or along the line of impact of two opposing currents. It is by such an explanation that Mr. Milne-Home and Mr. Jamieson would account for some of the long gravel ridges in different parts of the country. In some of the Aberdeenshire valleys, described by the latter observer, the gravel is arranged in such a way as to indicate the outward passage of a strong rush of water. It is often swept out of the narrower parts of glens, and in other places is arranged in ridges behind knobs of rock which look up the valleys. Mr. Jamieson suggests that during a rapid rise of the land or a series of elevatory shocks, the sea-waters rolled back, scouring out the glens, and heaping up sand and gravel in the lee of the opposing rocks.[2]

[1] *Ancient Sea Margins*, 1848.

[2] *Quart. Jour. Geol. Soc.* xvi. Milne-Home, *Brit. Assoc. Rep.* 1861. Sect., p. 115.

This explanation may account in part for the arrangement of the loose detritus in the Highland glens. It seems to me, however, that we must also take into account the possible freshets and floods which would arise whenever the covering of snow and ice in the higher parts of the country was rapidly thawed. Such vast bodies of water suddenly disengaged down the narrow valleys would produce many of the effects just described. Perhaps the true key to the origin of much of the Highland detritus lies in the adoption of both these hypotheses. In the next section of this memoir, I shall point out that the volume of water filling the Scottish rivers was, in all likelihood, very much greater during the later stages of the Drift period than it is now.

2. *Stratified Drift of Maritime Districts.*

Clay-beds of the Clyde.—These deposits have been classic ground to the geologist ever since Mr. Smith of Jordanhill announced the remarkable character of their fossil contents. They occur along the basin of the Clyde, on the low grounds that flank the river from the neighbourhood of Glasgow down to Greenock, beyond which they may be detected in most of the sheltered bays of the Firth. They fringe parts of the margin of Loch Lomond, and lie on some of the little islets of the lake. One of Hugh Miller's last geological excursions was devoted to tracing them between Loch Lomond and Stirling, and he succeeded in finding them at Bucklyvie. Along the shores of the Holy Loch, on the opposite coast at Gourock, and southward at Fairlie, all through the Kyles of Bute, and in every inlet of that island, in Loch Fyne at Lochgilphead, they may readily be found. The same deposits occur also on the west side of the Argyleshire peninsula at Oban, and northwards still, on the margin of Loch Eil, at Fort-William. Indeed, there is reason to believe that they extend under the bed of the Atlantic along the whole of our western coasts.

They are in most cases of a very fine texture, like consolidated impalpable mud. Beds of this description may be seen fifteen or twenty feet in thickness, without a single stone or shell. Above them lie other clays also fine in texture but containing shells and stones, with here and there a boulder, sometimes covered with striations, or mottled with serpulæ and barnacles, while in other localities the shells or the stones, or both, increase in number till they compose a considerable part of the bed. But even where they are most abundant the clay remains, as a whole, of the same fine texture, so that when the stones and shells are picked out it can be used for brick-making. These shells, as will be seen in the sequel, point to a much severer climate than that which now characterizes the area of Britain.

Along the higher reaches of the Firth of Clyde above Green ock, the stratified clay-beds occupy the low grounds bordering the river, and they never, so far as I am aware, reach a greater altitude than fifty feet above high-water mark. They are extensively used for the purposes of brick-making, and may be studied with facility in the clay-pits at Paisley and Houston. In making a recent excavation for a gasometer at Paisley, the following beds were passed through in descending order. For their description I am indebted to the Rev. W. Fraser, Paisley.

1. Dark earthy soil, passing down into gravel and sand, interspersed with stones, and containing two boulders, one of which was of great size,	3 feet 6 in.
2. Sandy clay without large stones, and containing no shells,	4 ,, 6 ,,
3. Thick bed of fine clay, interspersed with *Tellina proxima*, *Cyprina Islandica*, *Modiola modiolus*, *Pecten Islandicus*, *Trophon clathratum*, etc., and containing a good many angular stones, none of which were observed to be striated,	13 ,, 0 ,,
4. Laminated clay not pierced through, but so far as examined it contained no shells.	

Mr. Fraser informs me that here and there, at various depths, in bed No. 3, he found bands of shells, particularly the *Mytilus edulis*, crowded thickly together and perfectly preserved. The stones were often as angular at the edges as if recently broken, but never showed striations. They consisted of carboniferous limestone (containing *Rhynconella pleurodon*), quartzose sandstone, micaceous and red sandstone, ironstone, basalt, and quartzose schist. It is worthy of remark that nearly the whole of these stones may have come either from the south or the east; the geological formations of which they are fragments do not lie to the north or west. On many of them, as well as on the large horse-mussels, *balani* were noticed. My informant remarks that he also observed dark lines of earthy or rather carbonaceous matter stretching out from some of the stones, and apparently indicating the presence of sea-weeds attached to them.

From the same neighbourhood the Rev. Mr. Crosskey has kindly measured for me the subjoined section of the same clay-beds:—

1. Alluvial soil, ...	4 feet 0 in.
2. Littoral sand and gravel, with *Cardium edule* and pieces of wood bored by *Teredo*, etc.	0 „ 9 „
3. Clay without shells, ...	6 „ 0 „
4. Fine brick clay, with shells (a bed of *Cyprina Islandica*), not pierced through.	

Below both these sections, at a short distance, lies the stiff boulder-clay of the district. When I visited the clay-pits of this neighbourhood in September last, I found in one of them that the stones of the shell-clay were sometimes well rounded and smoothed like beach stones, and in one instance beautifully striated. Mr. Crosskey has since obtained several well-scratched boulders from the same clay, but they are certainly not common.

In the line of the Greenock and Glasgow Railway, a section was cut through a hill between Greenock and Port-Glasgow, in which Mr. Smith of Jordanhill found the following beds in descending order:—

1. Vegetable soil.
2. Coarse gravel, two feet.
3. Sand, ten feet. In neither of these strata did any organic remains occur.
4. A series of thin beds of sand, gravel, and clay, full of sea-shells. In this group he found thirty-three species.
5. Boulder-clay, of unknown depth.

These shelly beds lay about fifty feet above the level of the sea. Of the shells nearly a half were species not known to be living in the adjoining seas, but confined to much higher latitudes.[1]

Below Greenock the shell-clay is found between tide-marks at Gourock Bay. From this point down the Firth, its usual situation is on the beach, and only where the ground is low

[1] *Researches*, p. 32. I do not think it necessary to give lists of the shells in the text, as I have added to this paper a full catalogue of all the species which have been detected in the Scottish glacial beds up to the present time.

towards the shore does the clay extend inland. Along the greater part of the coast-line of the Firth of Clyde the land rises somewhat abruptly from the level terrace of the twenty-five foot raised beach, and the cliff which is thus formed has effectually prevented the clay from rising into the interior. In some localities, as at Balnakeallie Bay in the Kyles of Bute, the clay runs up from the beach for a short way into a creek of the shore. Here the singular contrast may be seen of a limpid streamlet running over the clayey bed of an old ocean, and washing out the shells that still lie in the positions in which they lived and died. In other places, where the ancient cliff-line sinks down into a low level flat, the clay is sometimes found in sinking wells or foundations, at a distance of a mile or more from the sea. It is, I believe, in this situation that it occurs in the neighbourhood of Stevenston in Ayrshire, where the ground is pierced for a coal-pit shaft.

In most of the less-exposed bays and inlets of the Firth, the shell-clay is probably to be met with. In one or two places, as at Ettrick Bay on the west side of Bute, I have seen it apparently in its last stage of decay. It had evidently, at one time, covered the whole beach, but it was washed off everywhere except under the lee of the scattered stones and boulders which had screened it from the waves. Along those parts of the shore where such boulders are absent, its destruction has probably been accelerated. At extreme low-water, it may be seen in many places on the Bute coast descending beneath the sea, though all trace of its existence has disappeared from the higher zones of the beach. In such localities the characteristic shells of the glacial period may be seen crowding the surface of the clay, and intermingled with the exuviæ of the living denizens of the Firth. The shells are often lying in the position in which they lived. This is especially to be noticed in *Mya Uddevallensis*, which, at extreme low ebbs, may be seen in scores standing upright in the clay as if it were actually the contemporary of the *Mya truncata*, which is still living in the same place, and bores into the same clay among its ancient congeners.

The occurrence of this shell-clay along the margin and the bottom of the sea, gives rise to two risks of error in observation. In the first place, the geologist who examines it on the shore requires to use the most scrupulous caution lest he include as fossil species shells which have been recently introduced into the clay by the action of the tides. I cannot but think that the list of glacial shells from the Clyde has been in this way unconsciously increased. And I could not have believed that the chance of error was so great, had I not had the good fortune to be guided over the deposits by my friend, the Rev. A. Macbride, of Ardmory, who has spent many years in quietly but sedulously exploring the glacial clays of his own neighbourhood. The other source of mistake is open to the naturalist, but is by no means so likely to mislead. In dredging over a part of the sea-bed, where glacial deposits containing shells occur, there is sometimes a tendency to forget their existence. Fresh-looking valves of *Tellina proxima* and *Pecten Islandicus*, for example, are thus dredged up along with living shells from the same sea bed, and unless the existence of the shell-bearing clays is kept in view, there is some danger of classing together, as contemporaneous, the organisms of two very distinct and widely separated periods in the geological history of the country.

The best section of the stratified clays which I have seen in the Clyde basin occurs at the Kilchattan tile-works in Bute, only a few feet above high-water mark. There the following beds are seen in descending order:—

1. Vegetable soil.
2. Sand and gravel, well-stratified, false-bedded, passing down into a sandy clay with gravel. . . . . . 10 or 12 feet.
3. Red clay without stones or shells, becoming dull olive green in lower part, ... 1 to 2 feet.
4. Bed of fine dark clay, full of *Tellina proxima*, etc., many of the shells retaining both valves, ... 2 feet.
5. Finely laminated brown and reddish brick clay, without stones or shells, ... 15 to 18 feet.
6. Hard tough red boulder-clay with striated stones; its upper surface hummocky and irregular.

The boulder-clay is of a red colour, and has a lumpy uneven surface on which the finely-laminated brick-clay rests. This brick-clay is entirely free from stones, and may be split up into thin layers indicative of a tranquil deposition. The shell clay is not laminated, but is exceedingly fine in texture. The shells abound, especially the *Tellina proxima*, of which the valves are frequently united, and still show their dark epidermis.

This order characterizes the glacial beds throughout the whole of the Bute coast and the opposite shores of Cowal. The red brick-clay sometimes dwindles down to only a few inches in thickness, but it is almost always found between the shell-clay and the hard till. It retains throughout the same colour, the same impalpable unctuous texture, and fine lamination. Its freedom from stones is remarkable. Nowhere have I seen a single pebble in it. Mr. Macbride, who has been looking at it for years, has been equally unsuccessful, and the workmen at the Kilchattan tile-works assured me they had never seen a single stone in this lower or brick-clay. The absence of shells is not less singular; after not a little inquiry I have been unable to ascertain the discovery in it of a single organism. Moreover, it appears to be very persistent in at least all the more sheltered parts of the Clyde basin. A fine laminated clay intervenes between the shell-beds and the underlying boulder-clay at Paisley. Round the whole of the coasts of Bute and on the Cowal shores, the invariable layer of fine, stoneless, and unfossiliferous clay is intercalated between the shell-bearing bed and the coarse, stiff, stony boulder-clay. The persistency of character of this clay-bed, and its extension throughout the basin of the Clyde, probably point to a uniformity of physical conditions in that area. The deposit must have been laid down with extreme slowness and tranquillity, as is shown by its fine inpalpable texture and minute lamination. It probably accumulated in a considerable depth of water, for it contains no interbedded layer of sand or gravel, such as might indicate a proximity to the shore. Yet it is found along high-water mark in localities where the ground rises with tolerable rapidity from the sea to a height of 800 feet and more. Even if it had been formed under a depth of 800 feet of water, its margin (now seen a little above high water mark) could not have been more in some places than a few furlongs from the nearest shore. If this clay has resulted from the deposition of glacial mud, either borne from the land by coast ice or washed off the seaward ends of glaciers by the action of waves and currents, it is difficult to understand why it contains no stones; for stone-laden fragments of ice could hardly fail to be drifted from the shore. Fine mud carried out to sea by rivers would be free from stones, or the waves acting on banks of boulder-clay might transport a large amount of fine sediment to deeper water. I am not sure, however, that these two agencies are sufficient to account for the existence of this fine clay. One thing at least seems certain, during the accumulation of this fine laminated clay, there could hardly have been much stone-laden ice drifting about on the Firth of Clyde. Perhaps the truth may be that this great land-locked arm of the sea was frozen over during the greater part of the period represented by the laminated clay, and that the south-westerly gales, though they may have broken up the ice in the main channel of the Firth, were unable to dislodge that which crusted over the more sheltered inlets, such as the Kyles of Bute, where, protected from wave action and from drifting ice, fine glacial mud was deposited over the sea-bed by submarine currents. But the question still remains, why is this laminated clay destitute of fossils? It was eminently fitted for their preservation had they ever been embedded in it. We cannot doubt, therefore, that they never could have been there, otherwise their remains would have been preserved as perfectly as those in the shelly clay which lies immediately above.

The clay in which the shells occur indicates a change in the physical conditions of the Firth during the accumulation of these strata. It usually contains stones; sometimes it is full of them. This is well seen in Kames Bay where the stones, though usually small, are thickly interspersed through a fine dark-coloured sandy silt. Some of the larger stones, perhaps six or eight inches in length, have the greater part of their surface covered with the *Balanus Uddevallensis*, which attains in the clay of this bay a greater size than in any other part of the Clyde. It does not appear that any instances have occurred of *Balani* crusting the under surface of the stones. I searched long and carefully for a striated surface among these stones, but without success. They are both rounded and angular, resembling in this respect the ordinary rubbish of the beach, where ledges of clay-slate are exposed to the waves and the weather. Yet it is remarkable, that notwithstanding this plentiful intermixture of stones, the clay is not commonly coarse and sandy. It never acquires the stiffness and the gritty earthy aspect of the boulder-clay. On the contrary, though sometimes mingled with sand and gravel, it retains on the whole the character of a fine silt. Nevertheless, the contrast between this clay and the laminated deposits on which it lies, is clear and abrupt. The shell-clay, as a rule, is not laminated; indeed it shows very scant traces of stratification. We pass at once from a fine fissile unfossiliferous clay (usually of a reddish tint along the Bute shores) up into a dark grey silt full of stones and shells.

There must thus have been a considerable revolution in the character of the agents which were carrying sediment across the bed of the Firth of Clyde during the accumulation of these strata. The gentle currents which carried the laminated clay were replaced by a more complex system of transportation. For it is evident that the currents, which were engaged in laying down the fine silt of the shell-bed, were wholly unable to move even the smallest pebble or stone which that stratum is now found to contain. Had the stones been borne to their present position by wave action, by ground swells, or by powerful submarine currents, it is inconceivable that they should be found lying in and wrapped round with fine silt. On the contrary, they would have been huddled together, and the silt would of necessity have been swept away. Besides, the condition in which the shells occur, at once disproves all violent action. They are in the most perfect preservation; their valves, seldom far apart, are frequently united, and often retain their epidermis even at the bottom of the bed, with numbers of stones around and above them. It seems undeniable, therefore, that some other agency must have been at work, quietly dropping stones, like those of the beach, upon the finer sediment that was gathering in still water. We shall, probably, not greatly err in ascribing no small share of this transportation to the action of coast-ice. Along the shores of Bute, as for instance in Kames Bay, the stones in the clay-bed are exactly such as a cake of ice forming on shore at the present day would lift up and carry seawards. Moreover, the coast-line, which is rocky, consists of soft clay-slate with veins of quartz, and gives rise to the formation of shingle and mud, but of hardly any sand. If a piece of coast-ice, therefore, were now to form on the shores of Bute, it would bear away angular fragments of slate and rounded pebbles of grit and quartz, but would rarely have its bottom coated with sand. Hence, almost the only foreign ingredients which would be mingled with the silt of the deeper water, would be the various pebbles and boulders of the beach--a circumstance which harmonizes well with the fine texture of the clay-bed, notwithstanding the number of its imbedded stones.

But besides the action of coast-ice, we must also take into account the effect of the waves, beating upon exposed banks of boulder-clay, and causing the finer sediment to be transported seawards. There may, likewise, have been a considerable quantity of fine sediment carried away from glaciers either by rivers, or, if the glacier reached the sea-margin, by the waves. In this way we may conceive that the Firth was discoloured throughout a large part of its area, by the glacial mud brought down from the surrounding glens. Such a condition of things is well explained by many parts of the Arctic regions at the present day. Thus, the great glacier on the south east coast of Spitzbergen runs for about thirty miles along the sea-margin in a line of precipice, rising from 20 to 100 feet out of the sea. "Much of the ice which floats away from these cliffs is heavily charged with clay and stones, and the sea for miles around is sometimes discoloured from the quantity of mud which is washed off this floating land-ice by the waves."[1]

If these suggestions appear reasonable, we may regard the stratified clays of the Clyde basin as having been formed during a gradually decreasing cold. At the beginning, the more land-locked inlets may have been permanently frozen over, and then the fine laminated clay gathered slowly under the ice over the surface of the submerged boulder till. As the temperature increased, this frozen envelope would be more and more broken up in summer; much coast-ice would thus be driven about the bays and kyles, and to this period we may ascribe the produc-

[1] Lamont. *Quar. Jour. Geol. Soc.* vol. xvi. p. 429.

tion of the shell-clays. While these changes were in progress, the general level of the land appears to have been rising. The same upward movement continued for an infinitely protracted period, during which the climate ameliorated, and the more boreal and Arctic forms retired from our seas to more congenial habitats in the far north.

It is deserving of inquiry, whether or not the fine laminated clay underlies the shell-bed in the more exposed parts of the western coasts, and if it exists there, whether it contains transported stones. The only locality of this kind which I have had an opportunity of examining, is on the flat mossy land between Crinan and Lochgilphead. Through the valley now traversed by the Crinan Canal, the full swell of the Sound of Jura and the open Atlantic beyond must have rolled into Loch Fyne. The glacial shell-bearing clay occurs in this hollow, and was recently well exposed in a deep drain near Lochgilphead, elevated only a few feet above high-water mark. The laminated clay is there absent, as the subjoined section will show :—

1. Vegetable soil.
2. Ferruginous gravel two to three feet.
3. Pale lead-coloured sand two to three feet.
4. Pale grey clay is an irregular stratum filling up hollows in the surface of the underlying deposit. It is full of the usual northern shells. (*See* Appendix.) The *Mya truncata* is especially abundant, rows of them standing together with their siphonal ends upwards, and boring into the surface of the boulder-clay below. So perfectly are they preserved, that the siphon itself still remains in the clay.
5. Pale grey boulder-clay, full of scratched fragments of various grits and schists.

It may be observed also, that when the stratified clays abut against the sloping banks of boulder-clay which rise upward from beneath the sea, there is of course an actual juxtaposition of the shell-bearing beds and the boulder-clay.

To some of the geological questions suggested by the fossil contents of these clays, I shall return on a subsequent page.

Shell-bearing Clays of Aberdeenshire, etc. The lower districts of Aberdeenshire,[1] bordering the sea, present a well-developed

[1] See Jamieson, *Quar. Jour. Geol. Soc.* vol. xiv. p. 509, from whose description the following account of the Aberdeenshire clays is compiled.

series of sands, gravels, silts, and clays, belonging to the marine or stratified Drift. This series attains a great thickness, sometimes exceeding one hundred feet. It ascends from beneath the present sea-level up to a height of at least 450 feet, but is chiefly developed in wide basin-shaped tracts on the lower grounds. Shells of an Arctic type have been found in it up to a height of 250 feet, thus linking it in true geological connexion with the clays of the Clyde.

In general aspect, it does not differ greatly from the character which the stratified Drift presents on the western coasts. It consists of alternations of fine clay and silt, with beds of sand and gravel. These are well shown in a section given by Mr. Jamieson, from the tile-work at Invernettie, to the north of Buchan Ness.

1. Blackish loamy earth, ...	1 foot.
2. Reddish brown clay, apparently devoid of stratification or lamination, and containing stones of various kinds, and of all sizes up to 4½ feet in diameter, often striated and grooved on the surface, ...	30 to 40 feet.
3. Clay of a brick-red colour and finer nature, and apparently free from boulders, ...	1 ,, 2 ,,
4. Very fine, laminated, dark-brownish clay, quite free from stones, ...	2 ,, 4 ,,
5. Fine brownish grey sand, devoid of all stones or pebbles of any kind; the bottom of it has not been reached, but it has been penetrated to a depth of . . .	20 ,,

The stony clay No. 2, presents several points of interest. Its boulders are of a heterogeneous kind, granites, schists, greenstones, sandstones, flints, etc. But they do not bear so large a proportion to the clay as to prevent the latter being used for brick-making after the stones are taken out. The largest block noticed by Mr. Jamieson, measured 4½ feet long, 2½ feet broad, and 1½ thick. It was rough and angular on all sides but one, which was smoothed and striated in the direction of the longest diameter of the block. Many of the stones, however, are striated on all their sides. In the same stony clay this observer found traces of broken shells, occurring in films of coarse reddish sand in various parts of the deposit, and a broken fragment of a shell was picked out of the fine clay No. 4.

At another tile-work, three miles west from Peterhead, a fine laminated clay is overlaid by a similar unstratified stony clay, in which blocks of three tons in weight are occasionally found. Boulders from two to three feet in diameter are frequently met with, and in a few instances the stones may be observed to be striated. This clay also contains shells, and when the stones are taken out is used for making bricks.

It will be apparent, from the description already given, that this clay differs essentially from the true boulder-clay or till. It is a fine brick-clay in which the stones are accidents, and its shells prove it to be a marine deposit. In short, it appears to have been deposited as fine silt at the bottom of a sea over which rafts of ice dropped the stones which they bore away from the adjacent land. The occasional striation of the boulders may have been produced either by coast-ice grating along the beach, or by glacier action, if the drifting ice came from the seaward extension of a glacier.

Along different parts of the eastern coast of Aberdeenshire, vast heaps of gravel and sand are found, apparently overlying the clays. They occur in mounds and long straggling ridges exactly like the kames already described. A good illustration is described by Mr. Jamieson, from the parishes of Slains and Cruden.[1] There, a range of gravel ridges, locally known as the Kippet Hills, runs with hardly any interruption in a zig-zag, tortuous, indefinite line for more than two miles. These ridges generally rise to the height of thirty or forty feet above their base; their sides are steep; their crest so narrow that two carts could barely pass each other on them; and their breadth is such that a stone could be easily thrown quite over them. They consist of sand, gravel, and water-worn pebbles, sometimes very coarse, and without any arrangement, sometimes finer, and passing into undulating sandy layers. Broken shells, such as the massive hinge of the *Cyprina Islandica*, occur both in the coarse and fine varieties.

In some localities the gravel ridges are dotted over with large erratics. This is conspicuously the case at the Menie Coast-Guard station, where boulders of trap, granite, and gneiss, some

[1] He is inclined to regard these mounds as older than the gravel which overlies the stratified beds at Aberdeen and elsewhere, and as perhaps contemporaneous with the stratified silts and clays which were laid down in deeper water.

of them six feet long, may be seen resting on the sides and summits of the mounds. In the same neighbourhood, the observer from whose description I quote, met with one gigantic boulder of granite measuring fifty-four feet in circumference, and rising about seven feet above ground. Another had a circumference of seventy-eight feet, and a height of six feet. These blocks are either rounded or rugged, with few sharp angles. No striations appear to have been observed upon them. But some miles farther to the north, at Cruden, a similar series of large blocks is scattered over the ground. These have been observed to be, in some cases, worn and striated on one side, which, it appears, is always the lower surface or bed of the stone.

The mounds of gravel are not only dotted over with large erratics (which are said also to occur occasionally in the interior of the ridges), but their surface is often obscured by a coating of red clay. This deposit is never of great thickness, and is generally absent from the higher mounds, or forms but a thin layer over them. In at least one example, near Menie, it has been observed encircling the base of a large block which lay immediately upon the gravel. In this case the sequence of events is very interesting. First, a series of mounds of shingle was thrown up probably along a coast-line, but during a time when the climate was so severe that masses of ice, charged with boulders, drifted over the sea. The stones thus transported, often of great size, were stranded upon the banks of shingle; and then it would seem that the sea-bottom was depressed to a lower level beyond the influence of the shingle-beating tides; that there it received a coating of red clay, which filled up inequalities of the old sand-banks and gravel mounds; and that finally the whole was re-elevated, and left beyond the reach of the sea.

The same series of stratified beds of sand and clay is found skirting the shore round into the Moray Firth. They have been long known at Gamrie, where Mr. Prestwich described them[1] as attaining in places a thickness of 250 feet, and rising 350 feet above the sea. Mr. Robert Chambers has likewise visited them, and published a section wherein numerous alterna-

[1] *Proc. Geol. Soc.* ii. 546.

tions of sand and clay, containing *Astarte arctica*, *Natica clausa*, *Tellina proxima*, etc., rest upon a fundamental deposit of boulder clay.[1] Some of the excursions that marked the closing years of the life of Hugh Miller were directed to this and some other localities for glacial shells; and in his collection he had a considerable number of well-preserved Arctic shells from the Gamrie beds.

These deposits run far up the valley of the Deveron and its tributaries. They occur, for instance, at Huntly, where Mr. Jamieson found them at a height of 360 feet above the sea-level. Up the course of the Spey they extend in terraces, which, at Rothes, rise nearly 400 feet above high-water mark in the Moray Firth.

Although the occurrence of the marine Drift has not, so far as I am aware, been recorded from the upper reaches of the Moray Firth, nor from the eastern coasts of Ross and Sutherland, there can be little doubt that it exists there. On the Caithness coast in the neighbourhood of Wick, occurs that curious unstratified fossiliferous clay which has been already described as probably coeval with the boulder-clay of other parts of Scotland. In the character of its fossils it resembles the ordinary stratified Drift. Mr. Peach has found it to contain forty species of various marine organisms. Those belonging to the mollusca are thirty-two in number, of which twenty-nine are species now living in the British seas, two Scandinavian, and one Arctic.[2] The height at which these remains are found in Caithness varies from 60 to 200 feet above the sea.

On the eastern coast from Aberdeen southward, shell-bearing clays of the Drift have hitherto been scarcely ever seen. Professor Fleming found some Arctic shells in a clay at Tyrie, near Kinghorn in Fife,[3] and true Arctic forms have recently been obtained by the Rev. Thomas Brown, from near Elie. At Dunbar, also, a number of beautifully preserved *Ophiuridæ* have lately been disinterred at the brick-works, but without any shells. This paucity of shell-beds in the Drift on the

[1] *Proc. Roy. Soc. Edin.* vol. iii. p. 332.

[2] *Brit. Assoc. Reports*, for 1862.

[3] *Lithology of Edinburgh*, p. 77. He found *Leda truncata*, a shell not now living in our seas, but still extant in those of the Arctic regions.

east coast may, however, be, to a large extent, due to insufficient observation.

Down the western coast of Scotland, although some of the fossil glacial shells are occasionally dredged in deep water, the shell-bearing clays of the Drift series appear to be but scantily developed until we reach the quiet sea-lochs of the Clyde. The Rev. Mr. Macbride informs me that this summer he found *Tellina proxima*, and other characteristic shells, in a clay on the coast at Oban. Mr. Jeffreys has also this year described a deposit containing similar shells near Fort-William. According to his observations, an elevated sea-bed, whose organic contents indicate a moderate depth of water, is there surmounted by a beach deposit containing littoral species. Nearly all the shells found here live in the adjacent seas, but a few of them now exist only in more northern latitudes.[1] Mr. T. F. Jamieson informs me that he has obtained *Natica clausa* and *Pecten Islandicus* from the raised beach, which corresponds to the forty-foot terrace of the west of Scotland. If these species were not washed out of the older sea bottom on which the raised beach deposits rest, their occurrence would indicate that the forty-foot terrace belongs to a part of the Drift period.

In the neighbourhood of localities where no shell-clays have been noticed, the operations of the dredge sometimes show that these deposits probably exist. Hence, it seems evident that the existing bed of the Atlantic, from the Shetlands south by Skye and the Hebrides to the Clyde, is still covered with the silt and shells of the glacial period. Single valves of shells, not known as living denizens of our seas, have been dredged up, sometimes in so fresh a state as almost to lead to the belief that the species can hardly be wholly extinct. Yet other valves, evidently of fossil specimens, are met with, and naturalists are therefore in the habit of regarding the shells as having come out of a deposit of the Drift series which forms the bed of the sea.

In this way we are led to perceive that it is only a part of the deposits of the glacial period which now appears on the land. What was the sea bottom then, remains to a large extent the sea bottom still. The changes in organic life which

[1] *Brit. Assoc. Reports*, 1862.

have taken place in the interval have gone on over the same area, species after species gradually dying out, and others taking their place round our coasts. Nay, the process of change must be going on slowly and imperceptibly still.

It is the province of the naturalist rather than the geologist to investigate the organic remains of these deposits, and to speculate from their peculiarities and mode of occurrence what may have been the nature of the climate, the depth of the sea, and the probable character of other physical conditions under which the organisms lived and died. Mr. Smith, of Jordanhill, has led the way into this fascinating field of research. But much remains to be explored. The minute history of the life of the period has still to be written, and doubtless many a deeply interesting page has yet to be added to the story of the glacial Drift.

Into the zoological problems suggested by the fauna of the marine Drift, however, I do not enter. Some of them have been discussed by Edward Forbes in his memorable paper on "The geological relations of the existing Fauna and Flora of the British Isles." And the subject is at present engaging the attention of others, who will, I trust, ere long, publish the results of their researches. In the meantime, the reader who is not familiar with the generalizations of Edward Forbes, must master them if he would acquire a philosophic view of the relation of the plants and animals of the Drift period to those inhabiting our islands at the present day.

In now drawing attention, however, to some general conclusions which the stratified Drift of Scotland appears to warrant, I may refer in a few words to the bearing of those fossils upon some of the geological questions which have engaged our attention in this Memoir.

Inferences deducible from the character of the stratified Drift.

In the foregoing pages reference has occasionally been made to the probable circumstances under which different parts of the marine sands and silts of the Drift series were accumulated. It may be useful to present here a general summary of the inferences which these deposits naturally suggest.

1. In the first place, when the stratified Drift was in the process of formation, the British Islands previously submerged probably 2000 feet below their present level, were rising above the sea. This upward movement was perhaps more continuous in its earlier stages, while towards its close, though the rate of rise may have been the same or even more rapid, it was interrupted by long pauses when the land remained stationary, and when in consequence lines of sea-cliff were eaten away, and terraces of littoral deposits were thrown down. After making every reasonable allowance for the wasting influences of nature, working through an indefinitely protracted period, we can hardly suppose that if the ascent during all save its closing scenes was extremely slow, and was marked by long pauses when the sea stood for centuries at certain levels, there would not have been more unequivocal traces of old cliff lines and raised beaches in the interior and upper parts of the country. It is undeniable that the nearer the lines of raised beach approach to the present sea-margin, they must remain fresher and more distinct, and that the higher they rise above that level, and the longer therefore they have been exposed to the rains and frosts, the less distinct will be their traces. It may be doubted, however, whether this is enough to account for the general absence of indubitable beach-lines over the greater part of the interior of the island. It is perhaps as likely that the rise of the land, even though progressing by intervals, with occasional interruptions of a retrograde kind, was yet on the whole so rapid as not to permit of the erosion of sea cliffs and the accumulation of well-marked littoral terraces.

But whether we hold that the movement was infinitely slow and continuous, or advanced in successive stages with long pauses between, or was accomplished by a series of quick upheavals or jerks, we must admit that while it was in progress, the mounds of sand and gravel, the huge erratic blocks, and the sheets of clay and silt which form the stratified Drift were accumulated. In the higher parts of the island, as we have seen, the evidence of the submergence is chiefly furnished by mounds of water-rolled gravel and sand, and by the dispersion of erratic blocks. These materials may in some instances have been deposited by rivers flooded by rapid thawings of the ice and snow of the uplands. Yet in other cases, even though they are associated with no marine organisms, they are seen to lie in places far out of reach of any stream, and on which only the waters of the ocean could have rolled. Beds of clay of marine origin are chiefly found at lower levels, especially close to the shore, whence they descend beneath the sea. It is in these clays, and more rarely in the mounds of sand and gravel which overlie them, that the organic remains of the stratified Drift occur. The sandy and gravelly nature of most of the Drift in the interior of the country, with the abundance of stratified clays in the tracts bordering the sea, is capable of several explanations. We may conceive the upheaval of the land to have been for the most part so gradual, that each successive deep-water deposit, as it came up to the level of the breakers, would be washed away, and littoral sand and shingle would be left in its place, while during the later stages of the elevation there were long periods of rest, between which the rate of rise was sufficiently rapid to allow large areas of the submarine silts to be upheaved beyond the reach of the waves. Or with perhaps less probability we may suppose that the clays were never formed save where we see them now, that is, in the extreme depths of the glacial sea, and that it was only towards the close of the long elevatory process that they were brought up to the light of day.

2. When these deposits were in the course of formation, the climate was so severe that both coast-ice and icebergs existed in abundance. This is shown by the scratched stones, by the large angular erratic blocks, and by the crumpled and contorted appearance of the sands and clays. Such proofs of a low temperature are not confined to any one part of the series of strata; they continue in some form or other from the highest point to which these beds have been traced, down to below the present sea-level. Glaciers too, as will be shown in the next section of this paper, existed in most of the higher districts of the country, and even pushed out their icy masses to sea. Hence the cold must have continued during the period of upheaval, gradually lessening as the land rose. The temperature of our area is still far from having regained the warmth which characterized it in the ages immediately preceding the commencement of that long

process of refrigeration which culminated in the glacial period. Hence it may still be growing insensibly more genial.

3. The nature and grouping of the beds composing the stratified Drift, afford on the whole evidence of regularity and tranquillity of deposition; they lend no support to theories of vast "waves of translation." It is possible that some of the phenomena of the kames above described, may be to some extent explained by the supposition of quick upheavals, or rather jerks of the land, whereby the sea was driven back with violence. But these are exceptional instances. The perfect stratification, current-bedding, and fine lamination almost everywhere visible, point to modes of accumulation such as are still going on in the seas around us.

If we pass to the consideration of the organic contents of these strata, we meet with similar evidence of quiet and peaceable agencies. The shells, in the great majority of cases, especially on the west coast, are not drifted specimens. This is shown by their perfect preservation, even the tender *Tellina proxima* retaining both its valves with their epidermis. The *Mya* is found boring in the clay with its siphuncular end uppermost, just as it died. The fragile *Balanus* may be seen thickly crusting the upper surface of a stone; had it been knocked about even for a short distance, it would have been detached from the stone, and have fallen to pieces. The same cirrhipede may be found in groups on the valve of a *Pecten Islandicus*, nay, I have seen it even on a specimen of that shell which had the two valves together, showing that the mollusc had lived and grown to a considerable size, with a heavy barnacle firmly attached to it. Indeed, the evidence which the shells afford of the tranquil character of the sea in which they lived, is of the fullest and most interesting kind.

It is true, that in certain localities the shells are frequently broken. In some of the clays along the Aberdeenshire coast, for instance, only fragmentary shells occur, and at Wick the same fact has long been noticed. From this circumstance, Edward Forbes inferred that icebergs or great waves of translation coming from the north, broke upon the northern shores of the British Islands, and gave rise to disturbed and unstratified deposits containing only broken shells, while in the quieter firths and creeks of the Clyde basin, protected by the Argyleshire mountains, the usual marine deposits went on without interruption, and the organisms of the sea-bed were buried in the places where they died.[1] This explanation may account in part for any difference which exists between the state of the shells in the sheltered parts of the Clyde and those in the more exposed coasts of Aberdeen and Caithness. But there is good evidence of a quiet sea-bottom during the glacial times, even on the shores of the north-eastern counties. The fine lamination of the clays there has assuredly not been produced or interrupted by "waves of translation." These deposits must have accumulated tranquilly on the sea-floor, over which icebergs and rafts of coast-ice, driven about by winds and waves, dropped their burdens of mud and boulders. It does not seem necessary to suppose the sea in any degree more buffeted by storms or stirred by earthquake waves than it is to-day, in order to account satisfactorily for the phenomena of the marine Drift, even on the northern coast of Scotland.

4. If during the period represented by the stratified Drift, the climate was of such severity as to cause the freezing of the surface of the sea, and to give rise to masses of drifting ice, it is natural to expect that some trace of this rigorous temperature should be seen in the remains of the organisms by which at that time the sea was tenanted. And this is found to be the case. I have already remarked that Mr. Smith, of Jordanhill, was the first to point out to geologists this interesting proof of a former severe climate in the British area. Since his observations were made, investigations have been carried on in many parts of these islands, as well as on the continent and in the far north. The result has been amply to confirm and extend Mr. Smith's conclusions.

It is now known that the fauna of the marine Drift is eminently of a northern character, indicating a temperature somewhat like that of the waters which wash the coasts of Greenland or of Labrador. Though the great majority of the shells found in these beds of clay and silt are also living in our seas, a small number are as yet unknown in the living British fauna. These were at first pronounced to be extinct species, but they

[1] *Mem. Geol. Survey*, vol. i. p. 384.

have almost all been since found alive in more northern latitudes. Such are *Mya Uddevallensis, Tellina proxima, Saxicava sulcata, Pecten Islandicus, Trophon scalariforme, Natica clausa*, etc. Other shells, though common in the Drift, now linger only in the deeper abysses of our seas, where, driven from all the higher zones of the sea in which they once abounded, they appear to be slowly dying out. Yet they still live in abundance in the boreal and Arctic seas. Examples are furnished by *Panopæa Norvegica, Puncturella Noachina, Nucula tenuis, Trophon clathratum, Natica pusilla, Trichotropis borealis*, etc. Moreover, those northern forms, which are still found in the profounder depths of the seas round the northern parts of the British Islands, are small and rare when compared with those of the same species which occur in the clay-beds. This is well shown by *Panopæa Norvegica*, which, though a very variable shell in the clay-beds of the Clyde basin, often occurs greatly thicker and stronger than any living example yet found in British waters. The fossils in this respect approach much closer to recent specimens from the Arctic seas than to those that have been dredged round our coasts. Sars has remarked the same difference between the fossils of the Drift in the south of Norway, and living specimens of the same species in the adjacent seas. He instances *Natica clausa* which, instead of occurring as a fossil in the rare and dwarfed state in which as a recent form it comes south to Bergen, is as large as the living individuals from Finmark and Greenland.[1]

A hardly less striking proof of the ancient rigour of the climate in this country is furnished by a comparison of those species which are still common round the coasts of Britain, and fossil specimens of the same species from the clay-beds. The latter are often greatly thicker and more massive than their living representatives, and this increase of thickness and size is sometimes (as in *Saxicava sulcata* and *Mya truncata*) carried to such an extreme, that at first sight we can hardly recognise the fossils as identical with the same familiar species of our present seas. Other instances are furnished by *Ostrea edulis, Pecten maximus, Cyprina Islandica, Modiola modiolus*, etc.

[1] *Jagttagelser over den Glaciale Formation; Universitetsprogram* (Christiania), 1860, p. 57.

5. The Crag deposits of the south-east of England unequivocally prove that the severe temperature of the glacial period did not come on suddenly, but that on the contrary, during a long course of ages, the climate gradually changed from one of a warmer character than we at present enjoy, to the intense cold of which the evidence is furnished by the phenomena of the glacial Drift. It is reasonable, therefore, to infer that as the cold increased by slow degrees, so by slow degrees it diminished. That this inference is probably correct is shown by the character of the stratified Drift of Scotland, as contrasted with that of the old boulder-clay. When the land rose again after the submergence, it was no longer wholly ice-covered; yet in its higher valleys it had numerous glaciers which protruded into the sea, while sheets of ice still formed along the coast-line. But though it may eventually be possible to show that the higher zones of the marine Drift indicate a severer temperature than the lower ones, and that the space between them contains evidence of a gradual amelioration of climate, such proofs have not yet been adduced.

When we examine a series of shell-bearing clays in any of the maritime districts, one of the first suggestions which present themselves is to determine the relation of these deposits to such recent marine strata as may be seen to overlie them. In such a succession of fossiliferous beds, can we trace any gradual change in the character or numerical porportions of the organic remains, indicating a corresponding change in temperature, depth, or other physical conditions of the ancient ocean in which the animals lived? So far as I am aware, no such gradation has been observed. Along the margin of the great basin of the Clyde, the old bed of the glacial sea, charged with its characteristic shells, still serves in part at least as the floor of the present sea, and where it slopes inland from the shore, it is found to be abruptly covered by the sands and gravels of the newest raised beaches, wherein all the shells are of species still inhabiting the Firth. In this district, therefore, there is no connecting link between the deposits of the glacial and those of the recent period.

The sharpness of this line of demarcation affords, however, no ground for the supposition that it indicates a corresponding suddenness of transition from the fauna or from the temperature of the ancient epoch to those of the modern one. It has been supposed, for instance, that the bed of the glacial sea must have been suddenly elevated into land, that the characteristic boreal and Arctic shells were thus exterminated from our area, and that the ground afterwards subsided to receive the deposits of the present ocean. This reasoning proceeds on the assumption that the geological records which we possess are a complete compendium of the physical revolutions of the globe. Yet a more thoughtful survey of the glacial deposits in their relation to the lines of raised beach, to the trend of marine currents and wave action, and also to the distribution of the present organisms of our seas, will probably convince the observer that the evidence is all in favour of a gradual transition from the climate and fauna of the glacial period to those of the present day. The hiatus between the deposits of the two eras will afford him only another proof of the fragmentary character of the annals from which geological history must be compiled; nor will he fail to perceive that if in a group of strata deposited upon each other in regular and apparently unbroken sequence, and so recent as almost to belong in a manner to his own times, so immense a gap can exist, he may well concede the possibility of an infinite number of breaks in the succession even of what may appear to be the most closely consecutive geological formations. The unrecorded ages of the geological past, from Cambrian times up until now, may thus vastly outnumber those of which a meagre and imperfect chronicle is preserved in the stratified crust of the earth.

The mere absence of intermediate strata between the glacial clays and the sands and gravels of the recent raised beaches is no proof that such strata never existed. On the contrary, if we reflect on the nature and origin of the raised beaches, we shall perceive that the chances of the preservation of any parts of such connecting strata must have been infinitely small. The twenty-five-foot terrace, resting as it does against a line of ancient sea-cliff, indicates that the land in its upward progress stood at this level for an incalculable number of ages. During this vast interval, the sea was beating upon the upraised parts of its former bed, in which the records of its inhabitants and their changes were preserved. It does not require a moment's reflection to see that the soft clays and silts could not fail to be washed away. Hence, not only such deposits as were formed after the close of the glacial period, and may have contained the organic evidence of the gradual amelioration of climate, but even large portions of the underlying glacial clays may have been entirely effaced. And in harmony with this probability, we find that the raised beach sometimes rests upon beds of clay overlying the glacial shell-bed; sometimes on that shell-bed, sometimes on the underlying, finely laminated clay, sometimes on the old till, while in other and more exposed localities, the whole of the Drift-beds have been swept away, and the raised beach rests on the solid rock. The same process of varying demolition can be admirably traced at present in progress along different portions of the Firth of Clyde. Thus, in Etterick Bay, on the west side of Bute, the westerly waves have entirely washed off the upper clay from the beach; the shell-clay is only visible here and there, under gravel and boulders; the laminated clay and the underlying till are likewise undergoing the same process; while in some places the whole of these clays have been removed, and the hard slates protrude upon the beach among the sand and gravel now thrown up by the tides. If a certain part of this coast-line were to be elevated, an observer might say that the period of the boulder-clay was followed immediately by that of the raised beach. If another portion were upheaved, he would find that between the boulder-clay and the raised beach there was an intermediate period, represented by the laminated clay. The examination of a third spot would show him that he required to intercalate another long interval, indicated by the shell-beds; while a fourth survey might reveal the existence of the clays overlying the shell-beds. After such repeated lessons he could not fail to learn that there might still be other missing portions of the series which he could not supply—portions perhaps as numerous and important as those which he had succeeded in discovering. In like manner, though no connecting links may be traced between the deposits of the glacial sea and the post-glacial raised beaches, we shall probably greatly err if we dispute their former existence, and seek by any sudden upheaval to account for the sharp line of demarcation between the strata of the two periods.

If we could examine the present bed of the Firth of Clyde, we should probably find there the missing part of the record. The glacial clays would be found covered by others of recent date, and the gradual changes from a more northern fauna to the present temperate one, would in all likelihood be indicated by a suite of well-preserved shells.

That the amelioration of climate and the change of marine life proceeded by a very slow gradation, is indicated by the present distribution of the mollusca of the British seas. It is now upwards of sixteen years since Edward Forbes described the existence of isolated groups of northern shells in some of the deeper abysses off the west coast of Scotland.[1] Such "boreal outliers" usually lie in a submarine hole or valley from 80 to beyond 100 fathoms in depth. "Their inhabitants," he says, "are decidedly of more northern character than the members of the Celtic fauna, and the species are such as are assembled together far to the north on the coast of Norway." An illustration of these features is afforded by the deeps of Loch Fyne, which were dredged by Forbes, with Mr. MacAndrew, in 1845. "The dredge," says the former naturalist, "brought up eight species of testaceous mollusca, one crustacean, and two echinoderms. Of these mollusca, five species were alive. One, a minute species of *Rissoa*, was new; the remaining four were *Nucula nucleu* (a northern variety), *Nucula tenuis, Leda minuta,* and *Lima subauriculata.* Of these, the number of examples of *Nucula tenuis* and *Leda minuta* exceeded greatly those of their companions; they are both essentially northern and Arctic forms, ranging from Greenland to the Scottish seas, and not known south of Britain. The *Nucula nucleu* and the *Lima* range from Greenland to the Mediterranean; but the variety of the former taken is confined to northern seas, and the latter is very rare, and only found at great depths in seas south of Britain. The dead molluscs taken were *Abra Boysii*, a species of similar range with *Nucula nucleu*; *Cardium Löveni*, a Scandinavian species, and *Pecten Danicus*, a Norwegian species,

[1] *Mem. Geol. Survey*, 1846, vol. i. p. 387.

found only, in the British seas, in the lochs of the Clyde, and there rarely alive, though dead valves are abundant, *as if the species thus isolated were now dying out.* The echinoderms were *Ophiocoma filiformis* and *Bryssus lyrifer;* the former a Norwegian species, the latter ranging to the Arctic seas, but southwards not known beyond the Clyde region. The crustacean was new, both as to genus and species. "It will be observed," he adds, "that the *assemblage* of animals thus taken at this great depth was essentially Arctic."[1]

The explanation proposed by the same naturalist to account for this isolation of northern forms in the deeper abysses of our seas was one of his most beautiful generalizations. He supposed the bed of the glacial sea to have been partially upheaved. This upheaval, by altering the level of all the still submerged portions, would produce marked effects upon the fauna of the different submarine zones. A number of the forms whose organization might be too delicate to endure the change of conditions, would be destroyed over the area of elevation, while another group, consisting of such species as had greater capacities for vertical range would survive. By this process, and while, owing to other and more general causes, the climate of this part of the globe became more genial, the more thoroughly boreal and Arctic forms which had lived in the upper zones of our seas during the Drift period, would be locally extirpated, and would be driven farther and farther north into more congenial temperatures. In the profounder deeps round our coasts, however, where the conditions of temperature would still remain suitable, northern forms would continue for a time to maintain their ground. The extreme scarcity of some of these northern mollusca in a living state in such abysses as those of Loch Fyne, and the comparative abundance of dead valves, seem to show, as Forbes suggested, that such species are slowly dying out. They have been able to maintain an unequal contest against the altered conditions of their places of abode, and we now see them in the last stages of their history as living British species.

These, and similar considerations arising out of a comparison of the distribution of the fauna now inhabiting the British seas, with the fauna which lived in them during the glacial epoch,

[1] *Op. cit.* p. 389.

afford a strong presumption, that the organic changes which have intervened between the two periods, have not been the result of any sudden catastrophe, but that on the contrary they have arisen gradually out of a complication of physical causes, and that they are even now in progress still. The history of our own country is thus a not uninstructive commentary on the larger history of the globe. We see, that here the existing period does not stand severed by any arbitrary line from those which preceded it, but that with these it is bound up by innumerable interlacing ties. We see too that it is a period of never-ending progression, carrying on, slowly and imperceptibly perhaps, yet not less certainly, those vast cycles of change which have been handed down from the past, and shall be transmitted as an ever-increasing legacy to the future.

III. —LOCAL GLACIERS.—FINAL DISAPPEARANCE OF THE ICE.

The continuance of a severe climate, when this country was undergoing its last great elevation, is well shown by the stratified Drift, of which the details have just been considered. The same fact is still further proved by the remains of true glacier moraines. To the evidence which the latter present we shall now turn.

If the whole of Scotland was submerged at the time of the greatest depression, it might be possible, even in the most elevated districts, to draw a line between the results of the old general glaciation which preceded the submergence, and that later localized glaciation which is now to be described. But in the absence of any certain proof that the whole country was under water, we are left to infer that, in the upland tracts, at a higher level than say 2000 feet above the sea, the great ice sheet, which covered all the mountains and descended upon the lower grounds in the early part of the Drift Period, never disappeared until it was gradually dissipated by the amelioration of the climate. Hence the rock-dressings produced in these high-lying districts by the old ice-flow probably merge, without any intervening traces of sea action, into those effected by the later glaciers. But in lower parts of the country there is clear evidence that the surfaces which had been striated by the great ice-sheet, went down beneath the sea-level, were there covered over with marine deposits, came up once more to the open air, and were ground down afresh by glaciers which, in place of spreading over the whole country, were confined to some of the corries and glens.

Great caution must thus be used in endeavouring to discriminate between the marks of ice-action anterior and those posterior to the stratified Drift. Rock-dressings in the valleys of mountain tracts can seldom be in themselves a sufficient guide; for the smoothing and striation produced within a confined area by the ice of the one period, would exactly resemble those produced by the ice of the period which succeeded, just as those of both these epochs are identical with the ice-work of the present day. Greater reliance may be placed upon the occurrence of perched blocks, while the existence of true terminal moraines completes the evidence. Blocks of rock poised on the edges of cliffs, or on the sides of steep declivities, can not have been subjected to any tidal action since their deposition there. If, therefore, such blocks occur in districts which can be shown to have been depressed beneath the sea during the glacial period, the inference is natural that their transport must have been effected by glaciers after the submergence. The same conclusion is borne out in a still more impressive manner by the existence of true glacier-moraines. The stratified Drift has been, as it were, ploughed out of the glens, and these later glacier deposits have been left in its place. Suppose, for example, that we find a moraine running across a Highland valley at a height of 300 feet above the sea; that we can trace true stratified Drift on the seaward flanks of the adjacent mountains, up to elevations of say 1000 or 1500 feet, but that in the bottom of the valley no vestige of this drift remains. From such facts, we conclude that after the land rose, a glacier descended this valley, swept out the marine deposits, and threw down its terminal moraine at a height of 300 feet above the sea. We thus obtain evidence of two glaciations: one general over the country prior to the submergence; the other local and subsequent to that submergence.

And this evidence is abundant in many parts of Scotland.

For the sake of a more convenient arrangement, its consideration has been deferred until after a description of the marine Drift. It is plain, however, that if the land never sank wholly beneath the sea, the islets which remained above water would be covered with snow and ice ; and that even if the submergence could be shown to have been complete, glaciers would form anew as soon as a sufficient area of gathering-ground had risen above the sea. Hence, contemporaneous with the loose floating ice, of which the marine Drift contains a record, there must have existed glaciers on the land. Moraines and perched blocks, at elevations of more than 2000 feet above the sea, may thus have been, to a large extent, if not wholly, contemporaneous with the formation of the marine Drift. Their testimony to the chilly climate of the glacial period is of a kind which may be conveniently studied by itself, and it acquires an additional interest, inasmuch as it reveals to us how, step by step, the ice slowly retreated, until, shrinking up into the innermost recesses of the mountains, it finally disappeared.

Proofs of the old glaciation are general over the whole island ; traces of local ice-fields and true glaciers, on the other hand, are confined to such hilly tracts as could give rise to independent reservoirs of snow ; they are, of course, never seen in the plains and wide valleys of the low-lying districts. Hence they occur sporadically in the mountainous parts of the country. True glacial moraines usually occur clustered together in the different valleys that radiate from a main mass of high ground. They are found at all heights, from 2000 feet or more down to within 30 or 40 feet of the present sea-level. Those nearest the sea must, on the whole, be oldest, though of course some glaciers would descend to a lower level than others, according to the size of the ice-basins which they drained and the nature of the surface over which they moved.

The chain of mountains extending from Ben Nevis to the north-east of Aberdeenshire, shows traces of several groups of glaciers. Others have radiated from the high grounds of Ross and Sutherland, and from the Cuchullin hills of Skye. In the south of Scotland, a smaller but well-marked series diverged from the uplands between the heads of the Tweed, Annan, Moffat, and Megget waters. And other groups of glaciers descended from other high lying districts of the island.

Observations have not yet been sufficiently extended and detailed to enable us to arrange the moraines in the different glens of Scotland into a general and connected system of glaciers. But the day is probably not far distant when the old ice-fields and ice-rivers of the Grampians and of the southern and northern counties will be mapped and described with almost as much certainty as are those now existing among the Alps. In the map which accompanies this memoir a few are inserted, more as an indication of how much in this department yet remains to be done, than as in any way aiming at completeness. Until a generalized view of the whole can be given, I think it best to limit myself to the description of two examples: one from the north-west Highlands, exhibiting in perfection the appearances of *roches moutonnées* and *blocs perchés*; the other, from the uplands of the south of Scotland, showing an admirable display of lateral and terminal moraines.[1]

1. Perhaps the best district in which to study the effects of the latest glaciation in abrading the rocks, and poising masses of stone on the verge of steep declivities, is the range of the Cuchullin hills in Skye.[2] This isolated cluster of dark, barren mountains rises in spiry peaks to a height of 3220 feet above the sea. In their recesses the numerous corries and glens present striking evidence of the former presence of glaciers. No better or more accessible example occurs than the well-known valley of Coruisk. From the margin of this small sullen tarn the mountains ascend in steep slopes and rocky precipices, seldom free from mist and rain. Its surplus waters find their way out in a brawling stream which, after

[1] It must be admitted that many of the examples of glacier moraines in Scotland, cited by Agassiz and Buckland, are really fluviatile or marine deposits. The first full and accurate description of a true Scottish moraine was by Sir Charles Lyell (*Geol. Proc.*, iii. 331) from the high grounds of Forfarshire. Principal Forbes, Mr. Chambers, Mr. Maclaren, and other observers, have traced them in other districts. But many remain still undescribed. Thus, in the autumn of 1860, I saw from the summit of one of the Beann Taobliath Hills, a vast but unrecorded accumulation of glacier mounds blocking up a glen between Loch Torridon and Loch Maree. For descriptions of glacial moraines, see the papers mentioned in the Appendix.

[2] Principal Forbes was the first to describe the glacial phenomena of this region. See *Edin. New Phil. Jour.*, vol. xl. p. 76.

a course of about a mile, enters the sea at the head of Loch Scavaig. On visiting Coruisk from the seaward side, one is struck at once with the smoothed flowing outline of all the bare ridges and hummocks of rock which abound in the bottom of the valley. The same swelling contour characterizes both the sides of the hills for a considerable way above the stream. The whole aspect of the rocks here differs so entirely from the character of the same rocks in the higher and opener parts of the mountains as readily to show that some agent has been at work smoothing over the sides and bottom of the valley, while the crags far above have been left rough and rugged with the scars of many thousand winters. The geological eye at once detects the track of a vanished glacier.

Nor does it require more than a casual scrutiny to note that the hillocks of rock are often elongated in a direction corresponding to that of the valley, that they are smoothed and rounded into a uniformity of surface truly astonishing, and that in many instances they present rough, rocky faces at their seaward ends, while towards the mountains they always slope gently away. These eminences, as well as the sides of the valley for some way up, are not only smoothed, but the surface of the rock is covered with parallel grooves or ruts and fine striæ, like those already described as so often underlying the boulder-clay. These markings may be traced along both horizontal and perpendicular faces of rock, and may even be seen mounting the sloping ridges. Everywhere in this wild scene, on the edges of cliffs and precipices, on the steep, bare sides of the hills, and on the top of the eminences in the valley, blocks of rock of all sizes up to masses of fifty tons in weight, may be seen perched with such apparent insecurity that a strong gale might almost hurl them to the bottom. When I visited Coruisk in 1857, with my lamented friend the late Captain Wood, R.N., a party of sailors from the gun-boat ascended unperceived to one of the rocky scarps on the west side of the lake. A noise like distant thunder, followed by a plunge of water, wakened the thousand echoes of this dark valley, and on looking round, we saw a second huge mass of stone flashing down the steep, grinding the rock into clouds of dust, and finally dashing into the lake. Several *blocs perchés* of considerable size, which, had they been lying on level ground, could not have been moved by the men, were thus, without much difficulty, hurled down the declivity. Several circumstances conspire to render the phenomenon of perched blocks peculiarly conspicuous in this valley. The hypersthene rock of which the mountains are composed, yields but slowly to the action of the weather. Bare of soil and barren of vegetation, the sides of these hills rise up in masses of naked rock, on which the impress of the glacier that once moved down the glen, lies as fresh as if the ice had only lately melted away. The boulders that strew the bottom of the valley, and stand poised along its flanks just where the glacier left them, are likewise fresh and bare. One can almost fancy that the disappearance of the glacier has been so sudden and so recent, that neither lichen nor moss, harebell nor heather, have yet had time to take root and lighten up the gloom of the glen with some faint gleam of life and beauty. Threading his way, indeed, among the fallen blocks and rounded knolls that border the river-course, he can half persuade himself that the next turn of the glen must reveal the glistening front of the glacier. But the source of the river is gained, and there, instead of the ice, lies the dark lonely loch, filling to the brim the basin which the ice ground out of the hypersthene, and surrounded by bare precipices and steep slopes that stretch away up into the heart of the mountains where the icy stream took its rise.

The glacial phenomena so well shown at Coruisk, have been observed by Principal Forbes to be reproduced in the wild corries on almost all sides of the Cuchullins. The great central group of mountains has in fact formed the source whence separate glaciers diverged towards the lower grounds. Thus at the foot of Corry Reaoch on the east side of Scuir-na Gillean, and along the mouth of the wild Corry-na-Criech on the north-west side of the hills, the valleys are blocked up by a wilderness of angular blocks from the high grounds, and their rocks are smoothed and striated like those of Coruisk. "But the most perfect union of all the appearances which recall the presence and action of a glacier, is in a deep corry immediately to the north west of Garsven, where the whole opening of the corry, which must have formed the channel of the glacier when it was present, is ground and shaven over in such a way as to leave not a single protuberance in the direction in which the ice-flood must have passed over it, whilst a band of transported blocks form, with surprising regularity, a kind of elongated semi-oval [a true terminal moraine] round the mouth of the corry, quite undistinguishable from those which a glacier would deposit under similar circumstances."[1]

2. Traces of local glaciers are not confined to the mountains of the Highlands. In the uplands of the southern counties, though the rocks have not often retained the polished and striated surface and the perched blocks just described, yet well-marked moraines occur, indicating the former existence of small groups of glaciers. In Galloway, as for instance round Merrick, they probably exist, but I have myself seen them only in the chain of hills which run along the confines of the counties of Lanark, Peebles, Selkirk, and Dumfries. This, with the exception of a part of Kirkcudbright, is the highest ground between the Grampians and the Cumberland hills, some of the ridges being more than 2700 feet above the sea. Here the Clyde, Tweed, Annan, Yarrow, and a host of tributary waters take their rise, flowing, some westwards to the Firth of Clyde, some eastwards to the German Ocean, and others southwards to the Solway. The hills for the most part have a flowing rounded outline, and are connected by flat-topped or saddle-shaped ridges usually covered with moss-hags. In some localities, as at the head of Annandale, in Talla Water, round Loch Skene, and in several of the glens that open into the Vale of the Moffat Water, the smooth contour of the hill-sides is varied by the occurrence of abrupt craggy scars and precipices, which present scenes suggestive rather of parts of the northern Highlands than of the soft pastoral air of the southern uplands.

In this elevated and lonely region relics of vanished glaciers are singularly clear. They may be seen in the upper parts of most of the wider valleys, as those of the Tweed, and Annan, and the Moffat, Megget, and Talla Waters. From the watershed between the Tweed and Annan, eastward to the Megget, the chain of high grounds, including Hart Fell and its offshoots,

[1] Forbes, *Edin. New Phil. Jour.*, vol. xl. p. 76.

seems to have been one great snow-field, sending down glaciers into the principal valleys. To the north, in the vale of the Tweed, where it is joined by the Fruid and Menzion Waters, mounds and hummocks of detritus and well-rounded knobs of rock are conspicuous. South of the Tweed water-shed, towards the mouth of the deep, caldron-like defile at the head of Annandale, known as "The Devil's Beef-Tub," similar mounds of rubbish are still more marked. But it is at the east end of the chain that the ice has left the most abundant and still uneffaced evidence of its presence. In the group of glens round Loch Skene, the phenomena of small and well-defined glaciers may be studied in abundant detail.[1] From these high grounds at least four systems of moraines, indicating the divergence of four separate glaciers, may be traced radiating to the north-east and south. One group extends down the Talla Water, beginning at a height of about 2000 feet above the sea. For 300 feet below the summit-level, the valley shows numerous bosses of rock, much weathered and decayed, but still retaining the characteristic rounded outline. It is then filled with mounds of rubbish, extending from the bottom up the sides for a distance of about 200 feet. These mounds present no very determinate arrangement, though, on the whole, they can be traced in rudely convex lines pointing down the glen. Enormous angular masses of rock lie strewn about on the tops and sides of the mounds, sometimes poised on the very verge, as if on the eve of rolling to the bottom. Between the mounds and ridges numerous hollows occur, more or less encumbered with peat and marshy vegetation. Some of these are complete basins, and are filled with water; while in winter, after heavy rains, a large number are converted into little tarns, so that when seen from above, the ground seems a network of pools. Such is the aspect of the valley of the Talla for nearly two miles, until at the Talla Moss, which is but little elevated above the stream, the valley divides, one branch going to the left down the Talla Linns, the other turning sharply to the right, and forming the head of the valley

[1] Mr. Robert Chambers has a brief allusion to some of the moraines of this locality (*Edin. New Phil. Jour.* New Series, ii. p. 184). This, so far as I have been able to ascertain, is the only reference to them on record. The remarks in the text are thus probably the first description which has been published.

of the Megget. Two or three ridges of rubbish, true lateral moraines, bend round to the east, and descend the Megget, while mounds of similar materials extend northwards towards the Linns. It appears, therefore, that a glacier filled the upper part of the valley of the Talla to a height of about 200 feet above the present bed of the stream, and that, on reaching the fork of the glen at Talla Moss, it broke against the opposing hill, and divided into two, one branch holding on down the course of the Talla, while the other turned eastwards into the valley of the Megget.

But the most striking traces of glacier action in these uplands lie to the south of the Talla. The water-shed at the head of that stream is formed by a ridge extending from Loch Craig to White Coomb in a semicircle, which, by sending out a huge spur from its centre, encloses the two deep corries of Loch

FIG. 7. Sectional view of Loch Skene

Skene and the Midlaw Burn. The recess in which the latter water takes its rise is walled in on all sides, save its opening to the south-east, by steep and even precipitous hills, rising on the west side into the White Coomb (2695 feet), and on the east into the Mid Craig (2207 feet), which separates this corry from the opener valley of Loch Skene. The bottom of the corry for about a quarter of a mile is a flat plain (about 1900 feet above the sea), from which the hills rise with singular abruptness. This plain has all the appearance of having been at one time occupied by a lake. Its lower end is barred across by a great convex rampart of earth and stones about forty feet high, pointing down the valley, and sloping away up on the north-east side into a well-defined ridge of the same materials, which runs along the hill that bounds the valley to the north-east. This transverse mound is a true terminal moraine; and the ridge on the hill-side above is, in like manner, a lateral moraine. The latter forms a singular feature when seen from the head of the glen. It looks as if a deep trench had been cut along the declivity, and the earth had been thrown over on the lower side, so as to form a prominent rampart. The hollow between this ridge and the hill on which it lies becomes evanescent at the upper end of the valley; but farther down it increases to 35 feet in depth, until the ridge is lost in the confused pile of mounds which descends towards the mouth of Loch Skene.

The terminal moraine has been sharply cut through by the streamlet. Mr. Chambers compares the ridge to an artificial dam with a sluice for the escape of the water. Indeed it can hardly be doubted that this great embankment did actually, at no very distant date, dam up the waters of a lake which replaced the old glacier. Beyond it several other less perfectly preserved mounds occur, pointing in like manner down the valley, and sloping upwards towards the lateral moraine. We then pass into an endless series of confluent mounds and ridges which completely choke up the valley, and descend to join another set of moraines that issues from the valley of Loch Skene. Through this mass of debris the Midlaw Burn has cut its way in a deep, sinuous ravine, which sometimes exposes a depth of fully 100 feet of loose unstratified earth and rubbish. Huge angular blocks of Silurian grit from the adjacent hills, some of them weighing 100 tons or more, are perched along the summits and outer slopes of these mounds. But in no case could I detect a single undoubted instance of striation among the stones of the moraines, nor, except in two or three places, on the rock below the moraine matter.

Loch Skene has been described by Mr. Chambers as a tarn dammed by a moraine. It might even be said to be enclosed by several moraines. On its northern and western sides the hills rise into steep cliffs, the Loch Craig being 2600 feet high, or 920 feet above the lake, which thus lies at a level of 1680 over the sea. To the east the loch is confined by a low bank, deeply covered with moss-hags. No rock can be seen in place; indeed, wherever the black peat has been washed off, it is moraine matter which is exposed. Moreover, one long bank of gravel and earth, with some large blocks on its top, rises out of the bogs. This ridge, known locally as "The

Causey," extends from the mouth of the lake along the peat-covered bank, nearly parallel to the edge of the water, for about 1000 feet, when it bends down the valley of the Winterhope Burn, and is soon lost beneath the peat. It is undoubtedly a moraine, thrown down, apparently, by a glacier which, descending from the head of the loch, broke upon the bank on which the "Causey" now stands, and sent one branch down the Winterhope Burn, where its mounds of rubbish are still abundant, the other down the Tail Burn, towards the cascades of the Grey Mare's Tail.

Where this Tail Burn issues from Loch Skene the concentric arrangement of the moraines, and the constant turning of their convex faces down the valley, are remarkably well shown. At the foot of the loch we see the fragments of one or two moraines, half submerged, and gradually being washed down by the water. Then comes a high bank of the same sandy clay and rubbish, with large angular blocks of stone scattered over its surface. From this point mound after mound may be seen crossing the line of the stream. I counted upwards of a dozen, until they began to lose their distinctness, and merge into confused piles of detritus. Here and there between the moraines, there are peaty and marshy hollows, which in winter are converted into tarns. On the east side of the stream, close to the foot of the lake, but about fifty feet above its level, there is a little tarn called "Hogg's Well," completely shut in by coalescing mounds. It lies, in short, in a cup-shaped depression in the moraines. On the ridge which encircles it, to the south, rests a block of grit, containing about 350 cubic feet.

Traces of ancient lakes dammed up by glaciers.—Loch Skene is an example of a sheet of water confined by the mounds of detritus shed from the end of a glacier. But it is conceivable that in some cases the glacier itself may have acted as the lake barrier. In the glens of Lochaber, and perhaps in some other Highland valleys, there occur terraces, like lines of ancient beaches, which, with a wonderful uniformity of level, run far up into the recesses of the mountains. These have been long known as "Parallel Roads." Many theories have been started to account for such platforms of detritus, the more commonly received explanation being that they represent lines of sea-beach during successive stages of the elevation of the land. But if this were true, they ought to occur in other glens in different parts of the Highlands, where the nature of the ground afforded at least equal facilities for their formation. They seem too fresh in their general appearance to be so old as such a marine origin would make them. I have already referred to the fact that the higher a line of raised beach lies above the sea, the more faint and evanescent must be its features. The forty-foot raised beach, for instance, though well preserved in some favourable localities, has disappeared, and is now disappearing, for leagues together, along the west coast of Scotland. The Glen Roy terraces, however, are actually more perfect than even the latest of the marine raised beaches. Yet the lowest is 850 feet above the sea-level, the second 1062 feet, and the third 1144 feet, and they retain their horizontality and persistence for many miles along the sides of the glens. Agassiz suggested, in one of the papers already quoted,[1] that these shelves were actually lake margins, and that the glens in which they occur had formerly been converted into lakes by having their mouths blocked up by the descent of glaciers from the adjacent mountains. This is probably the true explanation of these remarkable terraces. Mr. Jamieson, however, is at present making a renewed examination of them, and the results of his researches will, doubtless, before long be communicated to the Geological Society. If it shall be proved beyond a doubt that the Glen Roy shelves are truly the margins of an old glacier-lake, lowered to successive levels by the shrinking of the icy barrier, it will afford an additional and striking proof of the extent of the ancient Scottish glaciers. For such a lake must belong to the period which succeeded the marine submergence, that is, to the time when the ice existed sporadically among the mountain-ranges, and formed groups of glaciers which descended into the glens.

The proofs of glacier action to the north and north-east of Ben Nevis are of the most conspicuous kind. "I shall never forget," says Agassiz, "the impression I experienced at the sight of the terraced-mounds of blocks which occur at the mouth of the valley of Loch Treig, where it joins Glen Spean;

[1] *Edin. New Phil. Jour.* vol. xxxiii. p 217.

it seemed to me as if I were looking at the numerous moraines of the neighbourhood of Tines, in the valley of Chamouni."[1] Mr. Jamieson, in recently confirming and extending the observations of the Swiss naturalist, has pointed out the striking proofs which Glen Treig furnishes of enormous erosion by the downward movement of a mass of ice which abutted on the opposite side of Glen Spean. Although this able observer describes these appearances along with proofs of the general or old glaciation of the country,[2] the moraine mounds at the foot of the valley of Loch Treig, and on the flanks of Glen Spean, are probably proofs that a great mass of ice must also have occupied Glen Treig, and crossed to the other side of Glen Spean, during the period of local glaciers. We have thus evidence of the existence of ice in great mass in this district after the re-elevation of the land. The complete blocking up of Glen Roy and Glen Spean by glaciers, so as to give rise to a winding lake, is therefore far from being an improbable supposition.[3]

Volume of the Scottish rivers during the glacial period probably greater than at present.—Perhaps that feature of river scenery in Scotland, which of all others most forcibly and universally presses itself upon the attention of the observer, is the apparent inadequacy of the present streams to have produced the deep, wide valleys and ravines through which they flow. Even when in heaviest flood the great majority of them never fill their channels "from bank to brae." On the contrary, they meander along more like streamlets which have been shrunk by the long parching droughts of a rainless summer. So obvious is this character, that the popular belief has ascribed the dells and ravines to the agency of earthquakes and violent terrestrial convulsions antecedent to the human era. The form of the water-courses, however, is sufficient to satisfy a geological eye that it is not necessary to call in the agency of any subterranean movement to account for even the most precipitous defiles. These are evidently the result of erosion by running water, aided by frosts and the other usual

[1] *Edin. New Phil. Jour.* xxxiii. 222. [2] See *ante*, p. 25.

[3] For a list of authorities on the Parallel Roads of Glen Roy and other parts of Lochaber, see the Appendix.

accompaniments of atmospheric denudation. But is it likely that the present streams, operating with the same amount of force as they do to-day, could have carved out for themselves channels so much wider than they are ever now found to fill?

The immense erosive power of rivers can hardly be fully appreciated by any one who has confined his observations to the water-courses of Britain. It is in such districts as the uplands of Central France, where marine denudation has not come into play, that we learn, almost with a kind of awe, how potent is the long-continued operation of running water.[1] I am very far, therefore, from undervaluing the results which have been produced by the existing streams of Britain flowing with their present volume. Nevertheless, it appears to me that after the re-elevation of the country, the size of our rivers was much greater than it is now, and that their subsequent diminution has coincided with the general amelioration of climate, and the final disappearance of the ice. This inference rests upon the following grounds.

1. The water-courses are much wider than the present streams require or than they ever occupy. Even after we concede a vast lapse of time, and make every allowance for the tendency of all streams to wind from side to side, and thus to increase the width as well as the depth of their channels, we are forced, as it seems to me, to admit that the present amount of water in the streams seems very inadequate to produce the effects that are demanded of it.

2. The occurrence of alluvial terraces bordering a river, and sometimes 40 or 50 feet above its surface, indicate a marked change in the level of the river. This change can hardly be in every case one which has arisen merely from the deepening of the water-course, whereby the river has been lowered in level, while its volume may have remained the same. For these terraces extend from side to side of a valley which may be more than eight or ten times the breadth of the existing stream, and they consist of stratified detritus descending be-

[1] I cannot but think, however, that the continental rivers, like those of our own country, were greater during the later part of the glacial period than they are now, and that this may help to explain the enormous erosion which they have effected in districts which were not under the sea in any part of that period.

neath the present bed of the river. The whole of the terrace, therefore, which rises so high above the surface of the river, and stretches along either margin, consists of alluvium like that in the present water-course. Sometimes two or three successive terraces may be traced at different levels above the existing stream. If it be admitted, as it can hardly fail to be, that all this alluvium occupying the sides of a valley to the height of say forty or fifty feet or even more, has been assorted by fluviatile action, it is not easy to avoid the conclusion that the river must once have flowed with a far greater body of water than it does now.

3. Again, along the sides of valleys, even at greater heights than these terraces, there are patches of shingle and gravel very similar to the deposits of a river. The want of organic remains renders it impossible to ascertain beyond a doubt the nature of the agent by which these outliers have been formed. I believe the probabilities are in favour of a fluviatile origin, and if so, we have here another piece of evidence in favour of the greater volume of our rivers in former times.

It is not pretended that these reasons afford an indubitable proof of the inference in support of which they are here adduced. The subject is one on which I am still at work in the field, and I hope during the course of the ensuing summer to obtain more complete evidence. Along with proofs of augmented rivers, it may not be impossible to detect traces of such violent land-floods as have been already alluded to in this paper,—all pointing to the enormous amount of water which must have been discharged over the face of the country when the reservoirs of ice and snow melted away either gradually, during the progress of the seasons, or in sudden freshets caused by rapid thawings.

Evidence of Glaciers having reached the sea-margin.—In describing the stratified Drift, I had occasion to allude to the probability that, while that series of deposits was in the course of formation, glaciers actually protruded into the sea, and sent off detached masses of ice laden with detritus and blocks of rock. It is plain that the direct evidence of such a condition of things must be sought for where a Highland glen or corry opens towards the sea. Now, along the west coast of Scotland, at the head of the sea-lochs of Argyleshire and Inverness, we find traces of glacier action in the form of *roches moutonnées*, *blocs perchés*, and moraines, descending to within at least forty feet of the sea; that is, to the level of the raised beach which runs along the coast-line at that height, and which appears in some places to truncate the ends of the moraines. This is seen at Loch Scavaig, in Skye, at the head of Loch Eil,[1] in Glen Messan, near the Holy Loch, and probably in many other localities. The inference is, that when the land stood forty feet lower than it does now, glaciers actually reached the sea. But if this be true, it will also follow that the same seaward protrusion of the glaciers characterized the period during which were deposited the sands, gravels, and clays that cover the country down at least as far as forty feet over the present sea-margin; that is to say, nearly the whole of the stratified Drift of Scotland. The occurrence of Arctic shells in the forty-foot raised beach will, if fully established, afford additional and corroborative evidence of the severity of the climate at that time.[2] Thus, during the long process of upheaval in the course of which the stratified Drift was formed, the cold continued to be of great intensity; and it would appear to have remained so even when the land, having risen from a depth of perhaps 2000 feet, had come up to within forty feet of its present level.

If, then, glaciers actually descended to the sea-margin when the land had reached that stage of its upward progress, the evidence of their retreat, and of the final disappearance of the ice, cannot be older, but must be contemporaneous with or later

[1] Mr. Jamieson informs me that in this district the forty-foot terrace has cut into the moraine mounds. In Glen Messan the outer or lower moraines described by Mr. Maclaren actually come down close upon, if they do not actually reach, the twenty-five-foot terrace. The moraine character of these mounds, however, is hardly so satisfactory to me as to warrant any generalization from them. Perhaps a better section of them than is now to be seen might remove the hesitation. If it could be shown that these lower mounds, as well as those a little higher up the valley, are true moraines, we should be compelled to admit that glaciers continued to reach the sea during the rise of the land between the forty-foot and the twenty-five-foot raised beaches. See a paper of Mr. Chambers on this subject (*Edin. New Phil. Jour.* New Series, vol. i. p. 103), wherein he endeavours to show that glaciers came down to the sea in Arran even after the elevation of the twenty-five-foot terrace.

[2] See a reference to these shells, *ante*, p. 142.

than the line of raised beach which lies about forty feet above the present high-water mark. In other words, during either the long pause in the upheaval represented by that beach-line, or during the renewed ascent which left the land at the level of the twenty-five-foot terrace, or during both these periods combined, the vastly protracted ice-age came to a close. Not suddenly and sharply, however, did it terminate. It graduated by imperceptible stages into the present economy; and there yet live around us both plants and animals which, having survived the change of climate, still linger on as impressive testimony to the ancient rigour of our seasons.

Relation of Man to the Glacial Period in Scotland.—No evidence has yet been obtained in this part of the British Islands decisively to show that man had appeared here before the last glaciers had melted away. This is a question to which attention has recently been specially directed; and perhaps before many years are over, some progress may be made in arriving at a satisfactory conclusion in regard to it. In the meantime, it must be conceded that there exists no sound reason against the supposition that man may actually have inhabited Scotland during a part at least of the long glacial period. The only piece of evidence bearing on the subject with which I am acquainted is the discovery of a piece of artificially-worked cannel coal found in stratified gravel about fifty feet above the sea at Dundonald, in Ayrshire. This curious circumstance was mentioned to me by Mr. Smith of Jordanhill, who was assured by the person who found the relic that it lay under perfectly undisturbed marine deposits. If the forty-foot terrace be unequivocally proved to belong to the glacial period; and should it eventually be put beyond the possibility of doubt that articles of human workmanship occur in unbroken marine strata at a height of forty or fifty feet above the sea, it will follow that man lived along the shores of the British Islands when the cold was still so intense that snow-fields and glaciers occupied the high grounds. I would be sorry to lay too much stress on the discovery of this single human relic; but it is enough to put observers on the alert. No chance should be lost of carefully exploring every fresh section of Drift throughout the island.[1]

[1] In connexion with these raised beaches, I may refer again to the frequent

Close of the Glacial period.—Into the nature of the cause which brought about a gradual amelioration of the climate, it would be foreign to the scope of the present paper to inquire. The origin of the cold, and the reason of its cessation, remain as a fruitful source of conjecture. But no portion of the evidence in support of a former glacial period in this country is more impressive than that which reveals to us how, step by step, the cold grew less, the old mantle of ice and snow finally disappeared, and the land became clothed with the existing vegetation. This part of the story is told with singular clearness by many a glen and corry in the Highland tracts and in the uplands of the southern counties. We there see the old glacier moraines arranged concentrically within each other, mound after mound, getting narrower as they ascend the valley, and marking, by signs which cannot be mistaken, how the icy stream shrunk up into the mountains, till, along with its upper snow-fields, it finally melted away.

The vegetation of our islands, too, bears its testimony to the gradual change of temperature. Just as the northern shells have been driven from the upper zones of the sea until they now linger only in our deeper abysses, so the plants of a northern or Alpine character, retreating before the migrations of more temperate and southern forms, have gradually crept up into the high grounds, till now their remnants struggle to

occurrence of striated rock-surfaces at and even below the present sea-level. These markings are almost always far fresher there than at higher levels. One inference which may be legitimately deduced from this fact is the recentness of the last upheaval of the land. Down many of the fiords of the west coast the ice-moulded rocks may be seen sloping beneath the sea, and washed by its waves in storm and calm twice every twenty-four hours. Yet their finer striæ are still admirably preserved; a result which in some cases may be partly due to a thin but very hard film of cryptogamic vegetation. I know no better locality for studying these phenomena than Loch Riden, which descends from the mountains of Cowal into the Kyles of Bute. All the bosses of rock between tidemarks, and for about twenty feet above high-water line, are perfectly rounded, smoothed, and striated on the faces that look up the Loch. But from a height of about twenty feet or so above the level of high-water, the rounded outline becomes more and more broken, fissured, and disintegrated as we trace it up the hills. The rocks below that height must thus have been exposed to the destructive agencies of the weather for a very brief period indeed when compared with the rocks above. In other words, we have here a curious collateral and independent proof in favour of a modern date for the elevation of the twenty-five-foot terrace.

maintain a place upon the summits of our highest hills.[1] There the temperature is still chilly enough to allow the snow, in shady rifts that face the north, to remain for the most part unmelted all the year. But we can look forward to a distant time when, if the amelioration which has characterized the past shall continue in the future, the last of the Alpine forms will disappear, and the plants which now clothe our valleys will extend to the hill-tops, to be perhaps extinguished there in turn by the onward and upward march of other species from yet more genial climes. Thus once more do we hear those echoes of ceaseless change with which all the wide domains of Nature are ringing; echoes which, from rock and river, from lake and mountain, from valley and shore, yea, even from the depths of the sea, proclaim in a thousand tones that we do not live in an age of final consummation and perfection, but that the law of progress which, alike in the organic and inorganic worlds, has been the supreme law in the past, is the supreme law still, and that the task, as well as the noblest duty of man, is to aid in carrying out that law in the future, taking ever the lead of the wide creation over which he bears rule, and thus, as a fellow-worker with God, advancing to higher and yet higher stages of physical and intellectual development.

[1] See this subject happily treated in the paper by Edward Forbes previously quoted.—*Mem. Geol. Sur.* vol. i.

APPENDIX.

I. CATALOGUE OF ORGANIC REMAINS FROM THE GLACIAL DEPOSITS OF SCOTLAND.

The authorities consulted in drawing up the following list are—Mr. Smith of Jordanhill (*Researches in Post-pliocene Geology*); Professor Edward Forbes (*Memoirs of Geological Survey*, vol. i.); Forbes and Hanley (*History of British Mollusca*); Mr. T. F. Jamieson (*Quart. Jour. Geol. Soc.* vol. xiv., and in Smith's *Researches*); Woodward (*Manual of Mollusca*). In addition to these, the author has derived much valuable assistance from the Rev. A. Macbride, the Rev. H. W. Crosskey, Mr. C. W. Peach, Dr. Scouler, and the Rev. Thomas Brown, who have all added to the list of fossils from the Scottish glacial beds. The names of the shells are those of Forbes and Hanley, chiefly from whose work also the European range of the species is given. Species with an asterisk (*) are now extinct in the British area, but are found living in more northern latitudes. Those marked † are characteristically northern species still lingering in our waters, but apparently dying out there. Species enclosed within brackets [ ] have not yet been found alive, but some of them are possibly inaccurately determined. Unless where the deposit is otherwise indicated, the fossils are from the stratified Drift.

PLANTÆ.		
Nullipora polymorpha.	Clyde beds; Caithness (in the till).	
Quercus (oak).	Brick-clay, Portobello.	Associated with *Scrobicularia piperata*, *Turritella communis*, *Trochus cinerarius*, etc. The brick-clay in which these remains occur probably belongs to the closing part of the Drift period; but this is a matter open to discussion.
Betula (birch).	,, ,,	
Corylus (hazel).	,, ,,	
Cratægus oxyacantha? (hawthorn).	,, ,,	
Taxus baccata (yew).	,, ,,	
Pinus sylvestris (Scotch fir).	,, ,,	
Various rootlets and fibres of marshy vegetation, also seeds of a kind of whin? and roots of a heath?	Stratified beds in boulder clay of Slitrig, Carmichael Burn, and Chapelhall. Brick-clay between Newhaven and Edinburgh.	
Spores of a fern.	Stratified sands (100 feet above sea), Granton (determined by Dr. Young).	

AMORPHOZOA.		
Geodia. Clionia celata.	Caithness (in the till).	Found by Mr. Peach.
FORAMINIFERA.		
Polystomella crispa, *var.* striatopunctata.	Brick-clay, Annochie, Aberdeenshire.	Found by Mr. T. F. Jamieson.
Cornuspira foliacea.	,, ,,	,, ,, ,,
BRYOZOA.		
Hippothoa catenularia Membranipora Lepralia simplex, Lepralia Peachii,	Caithness (in the till).	Found by Mr. Peach, who says that the two species of Lepralia are thicker than recent specimens of the same species.
Flustra.	Lochgilphead.	
Tubulipora verrucosa.	Largs (Landsborough).	
ECHINODERMATA.		
Echinus (*fragments of plates and spines of at least two species*).	Kilchattan and Kames Bay, in Bute; Annochie, Aberdeenshire.	
Haploaster gracilis (*Allman*).	Brick-clay, Dunbar.	This new genus of Ophiuridæ has lately been found in considerable numbers and in wonderful preservation in the brick-clay of Dunbar. It will be described by Dr. Allman.
Psolus phantapus.	Brick-clay, Houston, near Glasgow; Bute.	First found by Mr. John Richmond of Rothesay in the clays of Bute, and recognised by Professor Owen (*Palæontology*, p. 37). Some beautiful specimens have lately been found by the Rev. H. W. Crosskey in the brick-clay of Houston.
ANNELIDA.		
Spirorbis corrugatus (*on* Pecten Islandicus).	Bute.	These need further investigation.
Spirorbis nautiloides.	Clyde beds; Stevenston.	
Serpula triquetra.	Dalmuir; Stevenston.	
Serpula vermicularis.	Lochgilphead; Caithness (in the till. Peach).	
Serpula, *sp.*	Stevenston (Landsborough).	
CIRRHIPEDIA.		
Balanus balanoides.	Clyde beds; Paisley.	Living in European and North American seas.
Balanus concavus?	Aberdeenshire (Jamieson).	
Balanus crenatus,* .	Dalmuir (Smith). Large Arctic variety in Kyles of Bute; the common form at Paisley (H. W. Crosskey).	Living in Arctic seas as far as Lancaster Sound (Smith).

Balanus Hameri (*syn.* B. Uddevallensis, *Linn.*)	Clyde beds. (The specimens from these deposits have not been certainly identified with this species.)	Mr. Darwin considers *B. Uddevallensis* as probably a synonym of his *B. Hameri*.
Balanus porcatus (*syn.* B. Scoticus).	Clyde beds: Elie, Fife; till of Caithness.	Northern specimens and those from the United States and from the glacial deposits often exceed in size living individuals from Great Britain and Ireland. Mr. Darwin considers *B. porcatus* and *B. Scoticus* (not *B. Uddevallensis*) as one species.
Creusia verruca.	Clyde beds.	Living in European seas.
CRUSTACEA.		
Carcinus mænas? (*fragments of the carapace and pincers*).	Bridge of Johnstone, near Paisley; Oban.	
MOLLUSCA. *Brachiopoda.*		
Hypothyris (Terebratula) psittacea.†	Ayrshire.	Rare in British seas, but more plentiful in those of Norway, Greenland, and boreal America.
Terebratula caput serpentis.	Ayrshire.	Ranges to Arctic seas; south of Britain only occurs at considerable depths.
Lamellibranchiata.		
Pholas crispata.	Stevenston; Aberdeenshire.	In the northern and Celtic regions of the European seas.
Pholas dactylus.	Stevenston.	Throughout the European seas.
Saxicava Arctica.†	Kyles of Bute; Lochgilphead; Aberdeenshire.	Ranges throughout the boreal and Arctic provinces of North Atlantic. Occurs rarely and of small size in the Mediterranean.
Saxicava rugosa [*syn.* S. pholadis].	Clyde beds; Elie, Fife; Aberdeenshire; Caithness (in the till). (The large northern form is a characteristic fossil of the glacial clays.)	Ranges throughout the boreal and Celtic regions of the North Atlantic.
Saxicava rugosa,* *var.* sulcata (*Smith*).	Kyles of Bute; Paisley.	Living in Davis Strait.
Mya truncata.	Abundant in the Clyde beds at Lochgilphead, Kyles of Bute, etc., rare at Paisley; Aberdeenshire. *Note.*—At Lochgilphead the syphon is preserved in the clay filling the interior of the shell. The specimens are usually larger than shells of living individuals.	Living in the Celtic and northern seas of Europe, the seas of Greenland, and of boreal America, as far south as Cape Cod.

Mya truncata.* var. Uddevallensis.	Kyles of Bute, Etterick Bay, and Kilchattan, in Bute; Lochgilphead; Caithness (in the till).	Living in the Gulf of St. Lawrence, and in the seas of boreal America and Greenland. This variety is extinct on the British coasts.
Mya arenaria.	Kyles of Bute.	Living in the seas of Northern and Celtic Europe, of Greenland, and of the coasts of Boreal America, as far south as New York.
Panopæa Norvegica.†	Clyde beds at Gourock, Fairlie, Kyles of Bute, etc.; Aberdeenshire; Caithness (in the till).	A very few specimens have been obtained off the coasts of Northumberland and Durham; otherwise it is not a British shell. Sars remarks that so rare is it, that only one living specimen has been found on the Norwegian coasts. Lovén says he has never seen more than one right valve taken by fishermen in the Cattegat.
Corbula nucleus.	"Scottish and Irish beds" (Forbes).	Living throughout the European seas.
Thracia phaseolina.	Kyles of Bute; Lochgilphead.	Ranges from the coasts of Norway to the Levant.
Thracia myopsis.*	Elie, Fife (Rev. Thomas Brown).	Living in the seas of Iceland, Greenland, and Spitzbergen.
Solen siliqua.	Clyde beds; generally in fragments only.	Living in all the European seas.
Psammobia Ferroensis.	Kyles of Bute (Crosskey).	Ranges throughout the European seas, but becomes scarcer as we proceed southward.
Tellina incarnata.	Kyles of Bute (Crosskey).	This is still found, though rarely, on the west of Scotland, but is on the whole, a southern shell, and a member of the Lusitanian fauna.
Tellina tenuis.	Taken from the glacial clay at the foundation of a bridge at Tignabruich, in the Kyles of Bute (Crosskey).	This littoral species ranges from the coasts of Finmark to the Mediterranean.
Tellina solidula [*syn.* T. Baltica].	Dalmuir; Aberdeenshire; Caithness (in the till).	Ranges throughout the European seas, and extends as far as the Euxine.
Tellina proxima * [*syn.* T. calcarea].	An extremely abundant shell everywhere in the Clyde beds; Elie in Fife; Aberdeenshire; Banffshire; Caithness (in the till).	Living in the Arctic seas. Not known as a living British shell, only a few single valves having been dredged in our seas, and these most probably fossil.
Tellina, *sp.*	Aberdeenshire (Jamieson).	
Syndosmya alba.	Clyde beds; Dalmuir: Lochgilphead.	Ranges throughout the European seas, from Norway to the Mediterranean. Larger in size as it goes north.

Syndosmya prismatica.	Clyde beds at Greenock; Lochgilphead.	Range similar to that of the last species.
Donax anatinus [*syn.* D. trunculus].	Stevenston.	Living throughout the Celtic and European seas, ranging to Senegal.
Mactra solida.	Stevenston; Kyles of Bute.	Ranges throughout the European seas.
Mactra elliptica.	Stevenston.	This shell ranges through the Celtic seas as far north as Finmark.
Mactra subtruncata.	Kyles of Bute (Crosskey).	Ranges from the Mediterranean to the south of Norway.
Mactra subtruncata, *var.* striata.	Dalmuir (Smith).	An aberrant variety of the last species, found living in Lough Strangford, County Down.
Lutraria elliptica.	Kyles of Bute.	Abundant 'round the British coasts. The fossil specimens are generally thicker and stronger than existing ones.
Tapes decussata.	"Scotch and Irish beds" (Forbes).	Living in the Celtic and south European seas. Sars says that it does not live on the Norwegian coasts, but is, on the whole, a southern form. Yet it occurs in the newer clays of Norway, where he has found it as large as the largest specimens seen by him in the Mediterranean.
Tapes pullastra.	Clyde beds.	Living in the Celtic and Scandinavian seas.
Tapes virginea.	Kyles of Bute.	Living throughout the European seas, but most plentiful in the Celtic region.
Venus striatula [*syn.* V. gallina].	"Common" (Smith); Kyles of Bute (Crosskey).	Living throughout the European seas.
Venus ovata.	"Irish and Scotch beds" (Forbes).	Ranges throughout the European seas, but chiefly in the Celtic and northern regions.
Artemis exoleta.	Clyde beds.	Ranges throughout the European seas.
Artemis lincta.	Clyde beds; Kyles of Bute; Caithness (in the till).	Ranges throughout the Celtic and southern regions of the European seas.
[Artemis laevigata.]	Stevenston (Landsborough).	"Examined by E. Forbes, who pronounced it a distinct species" (Smith). It does not occur in Forbes' list of glacial shells in the *Memoirs of the Geological Survey*.
Lucinopsis undata.	One specimen has been found by the Rev. Mr. Crosskey in the clays of the Kyles of Bute.	Ranges from the shores of Norway to the Ægean.

Cyprina Islandica.	Common in the shell-bearing clays, and generally larger than living specimens. In the Paisley clay there is one bed charged with this shell. Mr. Smith says he has found fragments of it in the "boulder-clay," and Mr. Peach has likewise found it in the till of Caithness.	Essentially a northern species, though not rare round the British coasts. It is common to the European and North American seas, and has a remarkably wide range in depth. "During the glacial epoch this and a few other boreal mollusca had extended their range to the Mediterranean, whence they have long disappeared, though their remains are preserved in the upheaved newer pliocene strata of Sicily."—F. & H.
Astarte sulcata [*including var.* Danmoniensis, *and* Scotica],	Clyde; Stevenston; Banff; Caithness (in the till).	Ranges all along the European coasts, but diminishes in numbers southwards from Britain.
Astarte crebricostata.	Dalmuir; Bute.	Only single valves have yet been dredged in British seas, and these have been but rare. It is found living off the coasts of Finmark, Spitzbergen, and Newfoundland.
Astarte elliptica.	Clyde beds at Paisley, Loch Long, Kyles of Bute, Lochgilphead; Aberdeenshire; Caithness (in the till).	A shell of the Celtic and northern seas; it occurs not unfrequently in the sea-lochs of the west of Scotland.
Astarte Arctica† [*syn.* A. borealis].	Clyde beds at Etterick Bay in Bute, Kyles of Bute, Gourock, Holy Loch, Lochgilphead; Aberdeenshire; Caithness (in boulder-clay).	One of the rarest of British living bivalves. Only two or three perfect specimens have been found. An inhabitant of the Arctic seas.
Astarte Arctica,* *var.* semisulcata (*Leach*).	Bute; Wick (Smith).	Said to abound in Davis Strait. Sars says it extends as far south as Bergen.
Astarte compressa.	Clyde beds, Paisley; Gourock; Kyles of Bute; Etterick Bay; Lochgilphead; Elie; Aberdeenshire; Caithness (in the boulder-clay).	Living throughout the Celtic and northern seas. A broader variety (*Crassina multicostata*, Smith) is described by Forbes [*Mem. Geol. Survey*, i. 413] as especially northern in the living state, and as the most abundant form in the glacial clays.
[Astarte propinqua] (*Smith*).	Stevenston.	Of this shell, Mr. Smith remarks: "Allied to *A. multicostata*, but with a much stronger hinge; it was submitted to E. Forbes, who pronounced it a distinct species."
[Astarte Uddevallensis] (*Smith*).	Dalmuir.	Named by Mr. Smith from its agreement with one of the Uddevalla fossils figured by Sir Charles Lyell.

Cardium aculeatum.	Stevenston (Landsborough).	This species is rightly a member of the Lusitanian fauna, and extends its range throughout the Mediterranean. It occurs on the South Devon coast, and is said to have been found also in the Hebrides and Orkneys.
Cardium echinatum.	Kyles of Bute; Lochgilphead; Caithness (in the boulder-clay).	An inhabitant of the European seas generally.
Cardium edule.	Clyde beds, not common; Caithness (in the boulder-clay).	This species ranges from the Celtic seas southward to the Canary Isles, and through the Mediterranean and Euxine to the Caspian. In the Arctic seas it is replaced and represented by *C. Islandicum*.
Cardium fasciatum.	Bute.	Ranges to the Norwegian seas.
Cardium pygmæum [*syn.* C. exiguum].	Paisley; Dalmuir; Bute; Lochgilphead.	Living in British seas whence it ranges to the Ægean, but does not appear to occur to the north of Britain.
Cardium Suecicum.	Kames Bay, Bute.	One of the rarest of British shells; out of Britain it occurs only in the Norwegian seas.
Cardium Norvegicum [*syn.* C. lævigatum].	Aberdeenshire; it occurs in single or broken valves in the Kyles of Bute; Caithness (in the boulder-clay).	Ranges from Norway to the Mediterranean.
Lucina borealis.	Gourock; Kyles of Bute.	A characteristic Celtic shell; it ranges to Finmark.
Lucina flexuosa.	Paisley; Lochgilphead; Kyles of Bute.	Ranges from Finmark to the Mediterranean.
Lucina ferruginosa.	Aberdeenshire.	Living off north-west coasts of Britain, also in deep water in the eastern Mediterranean.
Lucina (Cryptodon) *sp.*	Aberdeenshire (Jamieson).	
Kellia suborbicularis ?	Aberdeenshire (Jamieson); found in a fragmentary state, and its identification doubtful.	Living round British coasts.
Mytilus edulis.	Common in Clyde beds.	Living in seas of Celtic and northern Europe, coasts of Greenland and boreal America, also in Arctic seas.
Modiola modiolus.	Clyde beds; Dalmuir; Paisley; Kyles of Bute; Etterick Bay; Lochgilphead.	Ranges through the North Atlantic.
[Modiola albicostata] (*Smith*).	Dalmuir.	
Modiola, *sp.* (*Smith*).	Bute.	
Crenella lævigata.	Elie, Fife (T. Brown).	Living in the seas of Finmark, Greenland, Spitzbergen, Davis Straits, and Nova Zembla.

Crenella nigra.†	Kyles of Bute; one valve only (H. W. Crosskey).	A well-known inhabitant of the banks of Newfoundland, and in Europe of the boreal seas, whence it ranges south to the coasts of Scotland.
Crenella decussata.†	Elie, Fife (T. Brown).	Living off the northern coasts of Britain, and in the seas of Iceland, Greenland, and Spitzbergen.
Nucula nucleus.	Common.	Ranges throughout the European seas.
Nucula nitida.	Paisley (Crosskey).	Living round the British coasts and on those of Sweden.
Nucula tenuis.	Clyde beds; Aberdeenshire.	Living in the British (chiefly north), Scandinavian, Arctic, and boreal American seas.
Leda caudata.	Dalmuir; Kames, Kilchattan, Etterick Bay in Bute; Caithness (in the boulder-clay).	Rare on the south coasts of Britain; more plentiful to the north, whence it ranges through the Scandinavian and Arctic seas.
Leda pygmæa [*syn.* Yoldia (Nucula) pymæa].	Paisley (plentiful); Elie; Forfarshire; Aberdeenshire.	Living on Scandinavian coast, but also found in from 25 to 50 fathoms water off the north-west coast of Scotland.
Leda minuta.	Dalmuir; Aberdeenshire.	Living off the coasts of Finmark, Spitzbergen, and Greenland.
Leda truncata.	Tyrie, and Elie, Fifeshire.	Living in Arctic regions.
Leda oblonga [*syn.* L. rostrata, pernula].	Paisley; Kames Bay; Lochgilphead; Aberdeenshire.	Living in Arctic seas.
[Leda antiqua, *Smith*].		"Resembles the *Leda oblonga*, but is higher in proportion to its breadth and transversely striated" (Smith).
Yoldia, *sp. nov.*	Elie, Fife (T. Brown).	Living in the Heerloopen straits, Spitzbergen, in lat. 80° N.
Pecten varius.	Clyde beds; Dalmuir.	Ranges throughout the European seas; more common in the south than in the north of the British seas.
Pecten pusio [*syn.* P. sinuosus].	Dalmuir and other localities in the Clyde.	Ranges throughout the European seas.
Pecten tigrinus.	Loch Lomond beds.	Ranges throughout the Celtic and north European seas.
Pecten Danicus.	Loch Lomond beds.	Scandinavia to the Mediterranean.
Pecten maximus.	Fairlie, in Ayrshire; Etterick Bay; Kyles of Bute; Caithness (in the boulder-clay).	Ranges all along the Atlantic shores of Europe, from Norway to Gibraltar.
Pecten opercularis.	Kyles of Bute; Aberdeenshire; Caithness (in the boulder-clay).	Generally distributed throughout the European seas.
Pecten similis.	Fifeshire (Fleming).	Not rare round the coasts of Scotland.

Pecten Grœnlandicus.*	Elie (T. Brown).	Living in the seas of Russian Lapland, Spitzbergen, and Davis Straits.
Pecten Islandicus.*	Abundant in the glacial clays of the Clyde, but rare and small at Paisley; Fort-William; Aberdeenshire.	Living in the Norwegian, Greenland, and boreal American seas. Only single valves, and these exhibiting a fossilized appearance, have not yet been dredged up in British seas, so that it is not known to be now a living British species. Sars says it diminishes in size and numbers down the west coast of Norway, as far south as the Christiania Fiord.
Ostrea edulis.	Gourock; Etterick Bay; Kyles of Bute.	Ranges north and south from Britain, where it is chiefly developed.
Anomia ephippium.	Paisley; Kyles of Bute; Kames Bay; Lochgilphead.	Distributed throughout the European seas.
,, *var.* squamula.	Paisley.	
Anomia aculeata.	Stevenston; Paisley.	Throughout the North Atlantic.
Anomia patelliformis [*syn.* A. undulata].	Clyde beds.	Ranges throughout the northern shores of Europe.
Gasteropoda.		
Patella vulgata.	Clyde beds; Paisley (rare); Caithness (in the boulder-clay).	Ranges along the Atlantic shores of Europe.
Patella pellucida.	Dalmuir.	From the Norwegian seas to those of Gallicia.
,, [*var.* laevis].	Dalmuir; Banffshire.	
Acmæa virginea [*syn.* Patella (Lottia) virginea, Patella parva].	Dalmuir; Lochgilphead (plentiful).	Living throughout Celtic and Scandinavian seas.
Dentalium entale.	Aberdeenshire; Wick (in the boulder-clay).	General in the European seas.
Dentalium Tarentinum.	Gamrie.	Living in south British seas, whence it ranges to the Mediterranean.
Dentalium abyssorum [*n. s. Sars*].	Caithness (in the boulder-clay).	
Fissurella reticulata (*syn.* F. Græca).	Clyde beds (Smith).	Has been taken as far north as Stornoway, and cast on the shores of Orkney. Southwards it extends to the Mediterranean.
Puncturella Noachina† (*syn.* Cemoria Noachina).	Clyde beds; Lochgilphead.	Found sparingly off the coasts of Britain, chiefly in the north-west. Essentially a northern form, its chief habitats being in Arctic and boreal seas.
Trochus tumidus.	Clyde beds, Dalmuir; Kames Bay, Bute; Lochgilphead.	Ranges throughout the western seas of Europe.

Trochus cinerarius.	Stevenston ; Bute; Lochgilphead.	Ranges northward to the shores of Finmark, and southwards to the coasts of Spain.
Trochus zizyphinus.	Caithness in the boulder-clay (Peach).	
Trochus magus.	Clyde beds (Smith).	Not known north of the British Isles ; but ranges southwards to the Mediterranean.
Margarita (Trochus) undulata.†	Dalmuir ; Bute ; Lochgilphead.	An Arctic species, which comes south as far as the north and north-west coasts of Britain.
Margarita helicina.†	Oban.	Its range similar to that of the last species.
Margarita cinerea.*	Bute.	Found living in the seas of Finmark.
Littorina neritoides.	Paisley ; Kyles of Bute ; Lochgilphead (common).	Distributed all round the coasts of Europe, and extending through the Mediterranean.
Littorina littorea.	Clyde beds ; Paisley ; Lochgilphead.	Found along the Atlantic shores of Europe, and ranging southwards as far as Asturias.
Littorina rudis.	Clyde beds (Smith); Kames Bay, Bute ;	Its range similar to that of *L. littorea.*
Littorina patula.	Dalmuir ; Bute.	
Littorina littoralis.	Clyde beds ; Paisley ; Lochgilphead.	Ranges along the shores of the northern and Celtic provinces on the European side of the Atlantic.
Littorina palliata† [*syn.* L. Arctica, *Möller*].	Clyde beds (Forbes).	Living in Arctic seas and coasts of boreal America ; also occasionally found in British waters.
Littorina squalida.	Clyde beds ; Fort-William.	
Lacuna vincta.	Paisley ; Dalmuir ; Bute ; Lochgilphead ; Aberdeenshire.	Ranges all round the boreal regions of the North Atlantic.
Rissoa labiosa [*syn.* R. membranacea. *Lovén*].	Bute (Smith).	Ranges from the shores of Norway to the Mediterranean.
Rissoa ventrosa.	Dalmuir.	Found in many localities in the west of Europe.
Rissoa ulvæ.	Dalmuir.	Occurs all round the European coasts.
[Rissoa subumbilicata].	Dalmuir (Smith).	"An obscure species whose described characters are not very unlike those of *R. anatina.*"—F. and H.
Turritella communis.	Clyde beds ; Gourock ; Caithness (in the boulder-clay).	Generally distributed through the European seas, but chiefly characteristic of the Celtic and boreal provinces.
Turritella erosa ?* (*syn.* T. polaris).	Probably this species occurs in clay of Elie, Fife (T. Brown).	Living in the Greenland seas.

Aporrhais pes-pelecani.	Clyde beds; Gourock; Kyles of Bute; Aberdeenshire; Caithness (in the boulder-clay).	Inhabits all the coasts of Europe.
Cerithium reticulatum.	Lochgilphead.	Ranges from Norway to the Mediterranean.
Scalaria Grœnlandica.	Fairlie; Aberdeenshire.	A boreal and Arctic form, which has hitherto been found only in fragments in the British seas.
Natica monilifera.	Paisley; Gourock; Kames Bay and Etterick Bay, in Bute.	General throughout the Celtic region of the European seas.
[Natica fragilis (*Smith*).]	Dalmuir.	Considered by Forbes to be *N. monilifera*, much decayed.
[Natica glaucinoides. *Sow.*]	Aberdeenshire (Jamieson).	This species was also regarded by Forbes as identical with *N. monilifera.*
Natica nitida.	Aberdeenshire; Caithness (in boulder-clay).	Inhabits the coasts of Europe from Gibraltar to Bergen.
Natica Montagui.	Bute (Smith).	Appears not to range south of the Celtic region; ranges as far north as Bergen.
Natica helicoides.†	Bute; Aberdeenshire; Caithness (in the boulder-clay).	Rare in British seas; it is a boreal and Arctic species.
Natica sordida.	Caithness (in the boulder-clay).	Found (but rarely) in deep water round the British coasts.
Natica pusilla† (*syn.* N. Grœnlandica).	Bute; Aberdeenshire; Elie. (The fossil specimens resemble in size those living in the Scandinavian seas, and are larger than recent British forms.)	Very rare in British waters, where it ranges northwards to Greenland.
Natica clausa.	Common in Clyde beds, as at Paisley; Gourock; Kames Bay, and Kilchattan in Bute; and Kyles of Bute.	Living in Arctic seas and seas of boreal America. Sars says that it ranges south to Bergen, where it is rare and dwarfed. It is abundant in the older glacial clays of the south of Norway, where it is similar in size to the living individuals from Finmark and Greenland.
[Natica Smithii].	Ardincaple, near Helensburgh (Smith).	This species is not now known to be living. The original specimen from which it was determined was afterwards destroyed. With the exception of two specimens found some years ago at Rothesay, and believed by Mr. Smith to be *N. Smithii*, this species has never again been met with. See Smith, *Researches*, p. 52. Forbes, *Mem. Geol. Survey*, vol. i. p. 429.

Velutina laevigata.	Dalmuir (Smith).	Extends through the Celtic and boreal seas, along the shores of boreal America, and ranges throughout the Icy Sea.
Velutina undata, *Smith*.	Dalmuir.	Living in Davis Strait (Smith).
Trichotropis borealis.†	Bute; Cruden, Aberdeenshire.	Found, though rarely, throughout the Clyde region and the Hebrides, and off the east coast of Scotland as far south as the coast of Northumberland, whence it ranges throughout the boreal and Arctic seas.
Murex erinaceus.	Dalmuir.	Ranges from the Mediterranean to the coast of Denmark.
Purpura lapillus.	Loch Long; not common in Clyde beds (Crosskey); Caithness (in the boulder-clay).	Ranges along both sides of North Atlantic, and extends from the north-west coast of Spain into the Icy Sea.
Nassa incrassata.	Kames and Etterick Bays; Lochgilphead; Caithness (in the boulder-clay).	This is a Celtic mollusc in the main, but ranges northwards to the Arctic circle, and southwards to Madeira.
Buccinum undatum.	Paisley; Gourock; Kames Bay; Aberdeenshire; Caithness (in the boulder-clay).	Extends throughout the Celtic, boreal, Arctic, and Icy Seas, and along the coast of boreal America, from Cape Cod to Greenland.
,, *var.* striatum (*Sowerby*).	Dalmuir (Smith).	This species considered by Forbes as a variety of the foregoing.
Buccinum Humphreysianum.†	Bute.	Extremely rare in British waters; common in Arctic seas and on the banks of Newfoundland. Appears to be an Arctic form still lingering in our fauna.
Buccinum ciliatum.	Bute?	Living in Greenland seas (Woodward).
Fusus antiquus.	Paisley; Dalmuir; Gourock; Kames Bay; Kyles of Bute.	Typically a boreal and Arctic species.
Fusus propinquus.	Lochgilphead; Aberdeenshire.	Probably essentially a boreal species.
Fusus carinatus.	Aberdeenshire (Jamieson).	An Arctic species, apparently not now living in our seas.
[Fusus discrepans, *Smith*].	Dalmuir (Smith).	
Fusus curtus (*Smith*).	Stevenston (Landsborough).	Mr. Smith says this species is living in the seas round Nova Zembla and Greenland.
[Fusus, *sp. Smith*].	Stevenston (Landsborough).	
Trophon clathratus† [*syn.* Fusus imbricatus (*Smith*).]	Paisley; Kyles of Bute (abundant).	Ranges throughout the boreal and Arctic regions of the north of Atlantic. Sars says it becomes smaller and more scarce as it goes south from Finmark and Lofoden.

Trophon scalariformis † [*syn.* Fusus scalariformis (*Gould*). Fusus Peruvianus (*Lam.*)]	Dalmuir ; Paisley ; Kames Bay, Kyles of Bute ; Lochgilphead ; Aberdeenshire ; Caithness (in boulder-clay).	This may be only a large boreal variety of *T. clathratus* (F. and H. vol. iii. p. 438, note). It has been obtained off the coast of Belfast.
Mangelia turricula.	Bute ; Lochgilphead ; Oban ; Aberdeenshire ; Caithness (in the boulder-clay).	Essentially a northern shell.
Mangelia Trevelliana.	Aberdeenshire ; Caithness (in the boulder-clay).	This rare and local species is a member of the boreal element of the British fauna.
Mangelia rufa.	Kames Bay, Kyles of Bute ; Aberdeenshire.	More common in the south than in the north of the British seas. Occurs both sides of Atlantic.
Mangelia attenuata.	Kyles of Bute (Crosskey).	In the main a northern species. It ranges to the Mediterranean.
[Mangelia (Pleurotoma) discrepans (*Brown*).]	Dalmuir (Smith).	Living, but very rare in Scottish seas (Forbes' *Mem. Geol. Sur.* vol. i. p. 426).
[Mangelia, *sp.*]	Ayrshire (Smith).	"Allied to Brown's *Pleurotoma reticulata*. It is a very distinct species" (E. Forbes).
Cylichna alba.*	Clyde beds (Smith).	Living in the seas of Greenland, Finmark, and Spitzbergen.
Cylichna cylindracea.	Paisley ; Lochgilphead (Crosskey) ; Aberdeenshire ? (Jamieson).	Ranges from the North Sea to the Mediterranean.
Cylichna obtusa.	Aberdeenshire ? (Jamieson).	Generally distributed round the British coast.
Tornatella pyramidata.	Aberdeenshire (Jamieson).	
Cephalopoda.		
Nautilus Beccarii.	Dalmuir (Smith).	
PISCES.		
Fish-bones.	Brick-clay of Torry, near Aberdeen. (Jamieson, *Quart. Jour. Geol. Soc.* vol. xiv.)	
AVES.		
"Skeleton of a bird."	Brick-clay, Aberdeen. (Jamieson, *Quart. Jour. Geol. Soc.* vol. xiv.)	
Furculum of a gull ?	Brick-clay, Bridge of Johnstone, near Paisley (Dr. Scouler).	
MAMMALIA.		
Phoca vitulina ? (*seal*).	Brick-clays of Fifeshire and of Auchmacoy, near Aberdeen.	
"Bones of whale."		
Cervus Tarandus (*reindeer*).	Boulder-clay of Kilmaurs ; stratified clay in valley of the Endrick (with marine shells) ; bed of Clyde, opposite Jordanhill.	

Cervus elephas? (*red-deer.*)	Boulder-clay (Smith, *Researches*, p. 42).	Horns of this species, along with part of a rein-deer's antler, and a skull of *Bos primigenius*, were dredged up from the clay in the bed of the Clyde, opposite Jordanhill.
Cervus dama? (*fallow-deer*).	Boulder-clay (Smith, *ibid.*)	
[Cervus alces?* (*elk*).]	Marl beds of Perthshire (Smith, *ibid.*)	
[Megaceros Hibernicus? (*Irish elk*).]	(Smith, *ibid.*)	
[Bos primigenius.]	Clay in bed of Clyde, opposite Jordanhill; clay in Rothesay Bay.	
[Rhinoceros??]	Horns of this animal are stated to have been found in Scotland (*Mem. Wer. Soc.* vol. iv. p. 582; vol. v. p. 573), but the statement is very doubtful.	*R. tichorinus* has been found imbedded in the ice of Siberia, with the flesh and wool still covering the bones. It is now extinct.
[Elephas primigenius. *Mammoth.*]	Boulder-clay of Clifton Hall; Chapelhall; Kilmaurs; Bishopbriggs, near Glasgow.	The Scottish tusks are said to belong to this species. In the English bone caves it is found associated with remains of human workmanship. Like the woolly rhinoceros, it had a thick hairy covering to fit it for the regions of a severe climate. Its remains have also been found in abundance in Siberia. It is now extinct.

II.—LIST OF PAPERS RELATING TO THE GLACIAL PHENOMENA OF SCOTLAND.

1809. On the Old Alluvial Cover of Clackmannan. (Bald.) *Wernerian Memoirs*, vol. i. p. 841.

1812. On the Dressed Rocks of the Campsie Hills. (Imrie.) *Wernerian Memoirs*, vol. ii. p. 24 *et seq.*

On Revolutions of the Earth's Surface. (Hall.) *Trans. Roy. Soc. Edin.* vol. vii.

On a Perched Block near Dunkeld. (Macculloch.) *Edinburgh Journal of Science*, vol. iii. p. 46.

1817. On the Parallel Roads of Glenroy. (Macculloch.) *Trans. Geol. Soc.* First Series, vol. iv. p. 314.

1818. On the Parallel Roads of Lochaber. (Dick Lauder.) *Trans. Roy. Soc. Edin.* vol. ix.; *Edin. Phil. Jour.* vol. iv. p. 417.

1829. On a Large Greenstone Boulder on the Pentland Hills. (J. D. Forbes.) *Edin. New. Phil. Jour.* vol. vii. p. 259.

1830. Direction of the Diluvial Current in Shetland. (Hibbert.) *Edin. Jour. of Science*, New Series, vol. iv. p. 85.

1832. On a Large Boulder-stone on the Shores of Appin. (Maxwell.) *Geological Society's Proceedings*, vol. i. p. 402.

1836. On Changes of the Levels of Sea and Land in the West of Scotland. (Smith.) *Proc. Geol. Soc.* vol. ii. p. 427.

1837. On a Deposit of Shelly Clay in Banffshire. (Prestwich.) *Proc. Geol. Soc.* vol. ii. p. 544.

1838. On the Superficial Deposits of Mid-Lothian and East Lothian. (Milne.) *Trans. Roy. Soc. Edin.* vol. xiv. p. 307.

,, On the Last Changes in the Relative Levels of the Land and Sea in the British Islands. (Smith.) *Wern. Mem.* vol. viii.; *Researches in Newer Pliocene Geology* (Glasgow, 1862), pp. 6, 28.

,, On the Shells of the Newer Pliocene Deposits. (Smith.) *Brit. Assoc. Rep.* vol. vii. p. 87.

,, On the Composition of the Till near Glasgow. (Smith.) *Edin. New Phil. Jour.* vol. xxv. p. 383. See also this author's paper in the 8th vol. of the *Wern. Mem.*, and his *Researches*, p. 12.

1839. Observations on the Parallel Roads of Glenroy and of other parts of Lochaber, in Scotland, with an attempt to prove that they are of Marine Origin. (Charles Darwin.) *Phil. Trans.* 1839, p. 39.

,, On the Climate of the Newer Pliocene Tertiary Period. (Smith.) *Proc. Geol. Soc.* vol. iii. p. 118; *Researches*, p. 171.

,, On the Newer Tertiary or Pliocene Deposits of Scotland. (Smith.) *Proc. Roy. Soc. Edin.* vol. i. p. 263.

,, Alluvial Phenomena of Mid-Lothian. (Maclaren.) *Geology of Fife and the Lothians* (Edin. 1839), p. 207. Much of this article was published in the *Scotsman* newspaper in 1828.

,, On the Relative Ages of the Tertiary and Post-Tertiary Deposits of the Basin of the Clyde. (Smith.) *Researches*, p. 76.

,, Account of the Parallel Roads of Glenroy in Invernesshire. ("A Gentleman well known in Geology.") *Edin. New Phil. Jour.* vol. xxvii. p. 315.

1840. Observations on the Superficial Beds in the Neighbourhood of Glasgow. (Smith.) *Brit. Assoc. Rep.* vol. ix. Sect. p. 94.

,, On the Evidence of the Former Existence of Glaciers in Scotland, Ireland, and England. (Agassiz.) *Proc. Geol. Soc.* vol. iii. p. 327.

,, On the Former Existence of Glaciers in Scotland. (Buckland.) *Proc. Geol. Soc.* vol. iii. pp. 332, 345; *Edin. New. Phil. Jour.* vol. xxx. pp. 194, 202.

,, On the Geological Evidence of the Former Existence of Glaciers in Forfarshire. (Lyell.) *Proc. Geol. Soc.* vol. iii. p. 337; and *Edin. New Phil. Jour.* vol. xxx. p. 199.

1841. On the Boulder Deposits near Glasgow. (Craig.) *Proc. Geol. Soc.* vol. iii. p. 415.

,, On Newer Pliocene Deposits at Stevenston and Largs. (Landsborough.) *Proc. Geol. Soc.* vol. iii. p. 444.

1842. On the Glacial Theory [including a description of the Erratic Phenomena and Parallel Terraces of Britain]. (Agassiz.) *Edin. New Phil. Jour.* vol. xxxiii. p. 217.

1845. On the Scratched Boulders and Rocks of the Coal-field of Scotland. (Smith.) *Quart. Jour. Geol. Soc.* vol. ii. p. 33.

,, On Scratched Boulders. (Smith.) *Researches*, p. 127.

,, Notes on the Traces of Ancient Glaciers among the Cuchullin Hills, in Skye. (J. D. Forbes.) *Edin. New Phil. Jour.* vol. xl. p. 76.

,, On the Existence of Glaciers and Icebergs in Scotland at an Ancient Epoch, as illustrated by the Gareloch. (Maclaren). *Edin. New Phil. Jour.* vol. xl. p. 125.

1846. Remarks on certain Grooved Surfaces of Rocks on Arthur's Seat. (Fleming.) *Proc. Roy. Soc. Edin.* vol. ii. p. 67.

,, Traces of Glacial Action at North-Berwick and the Red Head. (W. C. Trevelyan.) *Edin. New Phil. Jour.* vol. xl. p. 387.

,, Notices of Polished and Striated Rocks near Edinburgh. (D. Milne-Home.) *Proc. Roy. Soc. Edin.* vol. ii. p. 95; *Edin. New Phil. Jour.* vol. xli. p. 206; vol. xlii. p. 154.

,, On the Connexion between the Distribution of the existing Fauna and Flora of the British Isles, and the Geological Changes which have affected their area, especially during the epoch of the Northern Drift. (Edward Forbes.) *Memoirs of the Geol. Sur.* vol. i. p. 336.

1847. Notes on the Superficial Strata of the neighbourhood of Edinburgh. (Fleming.) *Proc. Roy. Soc. Edin.* vol. ii. p. 111.

,, On the Parallel Roads of Lochaber, with remarks on the Changes of relative Levels of Sea and Land in Scotland, and on the Detrital Deposits of that country. (Milne-Home.) *Trans. Roy. Soc. Edin.* vol. xvi. p. 395; *Proc. Roy. Soc. Edin.* vol. ii. pp. 124, 132; *Edin. New. Phil. Jour.* vol. xliii. p. 339.

1848. An attempt to Classify the phenomena in the Glens of Lochaber with those of the Diluvium or Drift which covers the face of the country. (Sir G. S. Mackenzie.) *Edin. New Phil. Jour.* vol. xliv. p. 1.

,, On Diluvial Scratches on Rocks in the neighbourhood of Edinburgh. (Fleming.) *Proc. Roy. Soc. Edin.* vol. ii. p. 159; *Edin. New Phil. Jour.* vol. xlv. p. 171.

,, On the Parallel Roads of Lochaber. (James Thomson, M.A.) *Edin. New Phil. Jour.* vol. xlv. pp. 49, 404.

,, On the Transportal of Erratic Boulders from a Lower to a Higher Level. (C. Darwin.) *Quart. Jour. Geol. Soc.* vol. iv. p. 315.

,, On Scratched Boulders. (Smith.) *Quart. Jour. Geol. Soc.* vol. v. p. 17; *Researches*, pp. 134, 138.

,, Observations on the recent formations in the vicinity of Edinburgh. (Nicol.) *Quart. Jour. Geol. Soc.* vol. v. p. 20.

1849. On Grooved and Striated Rocks in the Middle Region of Scotland. (Maclaren.) *Edin. New Phil. Jour.* vol. xlvii. p. 161; *Proc. Roy. Soc. Edin.* vol. ii. p. 233.

,, On the Tertiary Deposits of the Moray Firth, etc. (Cumming.) *Quart. Jour. Geol. Soc.* vol. vi. p. 10.

1850. On the Till near Wick. (Cleghorn and Smith.) *Quart. Jour. Geol. Soc.* vol. vi. p. 385.

.. On the Occurrence of Marine Shells in Stratified Beds below the Till. (Smith.) *Quart. Jour. Geol. Soc.* vol. vi. p. 386.

.. On the Occurrence of Marine Shells in the Till. (Moore.) *Quart. Jour. Geol. Soc.* vol. vi. p. 388.

.. On the Glacial Phenomena round Edinburgh. (Chambers.) *Brit. Assoc. Rep.* vol. xix. Sect. p. 78; *Edin. New Phil. Jour.* vol. xlix. p. 330.

.. On Scratched Boulders. (Hugh Miller.) *Brit. Assoc. Rep.* vol. xix. Sect. p. 93.

.. On Glacier Moraines in Glen Messan, Argyleshire. (Maclaren.) *Brit. Assoc. Rep.* vol. xix. Sect. p. 90; *Edin. New Phil. Jour.* vol. xlix. p. 333.

.. On the Dispersion of Granite Blocks from Ben Cruachan. (Hopkins.) *Brit. Assoc. Rep.* vol. xix. Sect. p. 88; *Edin. New Phil. Jour.* vol. xlix. p. 334. See also vol. liii. p. 362.

1851. On the Till of Caithness. (Cleghorn.) *Quart. Jour. Geol. Soc.* vol. vii. p. 200.

.. On the Occurrence of Boulder-clay below Limestone near Elgin. (Brickenden.) *Quart. Jour. Geol. Soc.* vol. vii. p. 289.

.. On the Scratched and Polished Rocks of Scotland. (Murchison.) *Brit. Assoc. Rep.* vol. xx. Sect. p. 66.

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1854. On the Occurrence of Glacial Traces on the Rock of Dumbarton. (Brickenden.) *Quart. Jour. Geol. Soc.* vol. xi. p. 27.

1855. Further Observations on Glacial Phenomena in Scotland and the North of England. (Chambers.) *Edin. New Phil. Jour.* New Series, vol. i. p. 97.

.. On the Great Terrace of Erosion in Scotland, and its relation, date, and connexion with Glacial Phenomena. (Chambers.) *Edin. New Phil. Jour.* New Series, vol. i. p. 103.

.. Notices of Ancient Moraines in the Parishes of Strachur and Kilmun, Argyleshire. (Maclaren.) *Edin. New Phil. Jour.* New Series, vol. i. p. 189; *Proc. Roy. Soc. Edin.* p. 279.

.. On the Discovery of Calcareous Zoophytes in the Boulder-clay of Caithness. (C. W. Peach.) *Edin. New Phil. Jour.* New Series, vol. ii. p. 194.

.. On Glacial Phenomena in Peebles and Selkirk shires. (Chambers.) *Edin. New Phil. Jour.* New Series, vol. ii. p. 184.

.. Geological Notices of the Environs of Glasgow. (Bryce.) Glasgow: Griffin and Co. (re-published in his Geology of Clydesdale and Arran. Glasgow, 1859.)

.. On Striated Rocks in the north of Scotland. (Nicol.) *Brit. Assoc. Rep.* vol. xxiv. Sect. p. 88.

1856. On the Northern Drift of Morayshire. (J. Martin.) *Edin. New Phil. Jour.* New Series, vol. iv. p. 209.

1857. On a *Roche Moutonnée* on the summit of the range of hills separating Loch Fyne and Loch Awe. (The Duke of Argyll.) *Proc. Roy. Soc. Edin.* vol. iii. p. 459 ; *Edin. New Phil. Jour.* New Series, vol. vi. p. 153.

,, On Glacial Phenomena on Arthur's Seat. (Chambers.) *Proc. Roy. Soc. Edin.* vol. iii. p. 497.

1858. On the Pleistocene Deposits of Aberdeenshire. (T. F. Jamieson.) *Quart. Jour. Geol. Soc.* vol. xiv. p. 509.

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1859. On the Drift Beds and Boulders of the north of Scotland. (Jamieson.) *Brit. Assoc. Rep.* vol. xxviii. Sect. p. 114.

1860. On the Drift and rolled Gravel of Aberdeenshire. (Jamieson.) *Quart. Jour. Geol. Soc.* vol. xvi. p. 347.

,, The Old Glaciers of Switzerland and North Wales. (A. C. Ramsay.) London, Longman and Co.

1861. Ice and Water, a review of the Superficial Formation. (Chambers.) Edin. 8vo, pp. 45.

,, Notice of the Elongated Ridges of Drift in Scotland called Kames. (Milne Home.) *Brit. Assoc. Rep.* vol. xxx. Sect. p. 115.

1862. On a Split Boulder in Little Cumbra. (Smith.) *Quart. Jour. Geol. Soc.* vol. xviii. p. 162.

,, On the Ice-worn Rocks of Scotland. (Jamieson.) *Quart. Jour. Geol. Soc.* vol. xviii. p. 164.

,, On the Glacial Origin of Lakes. (A. C. Ramsay.) *Quart. Jour. Geol. Soc.* vol. xviii. p. 202.

1863. On the Antiquity of Man. (Lyell.) Chap. xiii.

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